Old Croton Aqueduct,
Ran from Croton River to Central Manhattan.
Dobbs Ferry, Hastings-on-Hudson, Irvington,
North Tarrytown, Ossining, Yonkers, Yorktown
Heights, New York City.
Bronx, New York, and Westchester Counties
New York

NY-120

HAER,
NY,
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84-

REDUCED COPIES OF MEASURED DRAWINGS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

PHOTOGRAPHS

Historic American Engineering Record
National Park Service
Department of the Interior
Washington, D.C. 20240

HAER,
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HISTORIC AMERICAN ENGINEERING RECORD

NY-120

OLD CROTON AQUEDUCT

Date: project initiated 1833; opened in 1842.

Location: Ran from Croton River to Central Manhattan, Dobbs Ferry, Hastings-on-Hudson, Irvington, North Tarrytown, Ossining, Yonkers, Yorktown Heights, and New York City; Bronx, New York City, and Westchester Counties, New York.

Engineer: John B. Jervis

Owner: Originally; New York City Water Board
Presently; In Westchester County, Tatonic State Parkway Authority; In New York City, Dept. of Parks and Recreation.

Significance: The Old Croton Aqueduct was New York City's first municipal water supply project, and is an outstanding example of early 19th century civil engineering.

Historian: Larry D. Lankton, 1976.

Transmited by: Daniel Clement, 1984. For further information regarding the Old Croton Aqueduct please refer to HAER NY-107 through NY-119.

CHAPTER ONE

In the summer of 1836 Stephen Allen was anxious to get started. The Democrat, Chairman of New York City's Board of Water Commissioners, wanted construction to begin on the Croton Aqueduct. He wanted an army of Irish laborers to invade Westchester County and set up shanties near the Hudson River's stately manors. Allen wanted to see shipments of brick, stone and cement ply the Hudson, while the Irish wielded picks and shovels. He wanted to see the Croton River cut by a tall stone dam; hills pierced by deep excavations or tunnels; and valleys, including the Headless Horseman's Sleepy Hollow, spanned by a masonry conduit that would carry much needed water to Manhattan. Unfortunately, Allen was not only anxious; he was disappointed, frustrated and angry that he had to wait still longer to see these things. He felt he had waited too long already.

Three years earlier the state legislature had encharged Allen's Board of Water Commissioners with the task of deciding how to supply New York with an abundance of wholesome water. The Commissioners hired consulting civil engineers, undertook feasibility studies, and twice they reported that New Yorkers should turn to the Croton River. This was a bold decision, because the Croton was far-removed from Manhattan. It sprang from lakes and ponds located fifty miles north of the island. Three of the Croton's branches, the West, Middle and East, converged near Owen Town. From there the river ran southwestward through Westchester County, flowing into the Hudson at a point 25 miles from Manhattan's northernmost tip. Despite the Croton's remoteness, the Water Commissioners insisted upon drawing water from tl river and they expressed full confidence in the city's ability to construct a 41-mile-long aqueduct running from the Croton to central Manhattan.

From 1833 to mid-1835 the Croton Aqueduct was just an idea contemplated by the Water Commissioners and their consultants. Then, after receiving the endorsement of the city's voters and the Common Council, the Commissioners moved to make the Croton Aqueduct a reality. On June 2, 1835 they hired Major David Bates Douglass as Chief Engineer. Douglass, a former professor of civil engineering at West Point, had served as the Commissioners' most influential consultant. He had studied the aqueduct's feasibility in 1833 and 1834. With surveying parties he had trod every foot of its proposed route, and he had prepared tentative designs and cost estimates. So in the summer of 1835, with Douglass in command of the engineering corps, Stephen Allen and the other Commissioners looked forward to a prompt execution of the work. But by late summer in 1836, the Croton Aqueduct was still an idea only partially formulated in the head of the Chief Engineer. Major Douglass had not broken ground.

Stephen Allen was rightfully impatient, not only because Douglass had failed to break ground, but because prior to 1836 New Yorkers had suffered for over half a century from an inadequate water supply. Since 1774 engineers and opportunists had projected a plethora of Manhattan water supply systems. But most were never to be built, and the few that were did little to remedy the problem. Stephen Allen was a proud politician. Characterized by his friends as strong-willed, and by others as hard-headed and opinionated, Allen the public servant wanted New

Yorkers to benefit from a well-engineered water system, just as Philadelphians already benefited from their Fairmount Water Works along the Schuylkill River. And Allen the politician wanted credit as the chief administrator of such a fine and important work. He did not want to become known as the progenitor of yet another failure.

When it came to providing its inhabitants with water, Manhattan was a geographic irony.[1] It was enticingly surrounded by the Hudson, East and Harlem Rivers, but they were brackish. Because of the Atlantic's tides they contained salt water unfit for domestic use. So from the very start, Manhattan's Dutch and English settlers had drawn their water from springs, ponds, wells or cisterns.[2] In the earliest years of settlement this simple and old water-gathering technology sufficed. But by the mid-1700's serious problems began to arise. In 1748 a visitor to New York asserted that "There is no good water in the town itself."[3] Brackish water contaminated the wells on Manhattan's perimeter. Meanwhile, interior wells were polluted by the seepage from privies, cess pools and graveyards, and by the run-off from fouled streets. The city's water supply deteriorated because its simple water-gathering technology conflicted with an equally primitive technology of public sanitation.

Despite the seriousness of the problem, New Yorkers were dreadfully slow in changing how they got their water. They did not adopt a new technology. Instead, they made facile accommodations. Many simply grew accustomed to the foul taste of their water. Others resorted to ever-deeper wells, to wells or springs located further from the population center, or to water purchased from street vendors. These accommodations were often incovenient, and sometimes very dangerous. Residents were more exposed to contamination and disease; a filthy urban environment prevailed because of inadequate cleaning; and citizens and structures alike were constantly threatened by the ravages of fire.

A 1776 fire destroyed one-fourth of the city's homes. An 1828 fire destroyed some $600,000 worth of property, and in 1835 yet another fire leveled twenty blocks and claimed 670 buildings. Disease, too, took its toll. In 1798 a yellow fever epidemic killed 2,000, and even in "ordinary" years the death toll ran high from yellow fever, typhoid and cholera.[4] In 1832 Asiatic cholera struck New York in July, and citizens hastily attempted to minimize its effect by cleaning the city and improving health conditions. Their efforts failed. One-hundred thousand persons fled to avoid the pestilence, and yet by late October 3,500 had died.

While periodic catastrophes struck the city, the quality of its existing water resources continued to decline. Manhattan's population, clustered on the southern end of the island, increased at an overwhelming rate. In 1790, some 33,000 persons lived in New York. In ten years that figure doubled to 66,000. By 1810, 96,000 inhabited the city, and between 1810 and 1830 the population jumped to 202,000. This population explosion had a direct and deleterious effect on the city's water. By 1830 residents dumped one-hundred tons of excrement per day into the same sand bank from which they drew their water.[5]

Against this background, it is no wonder that in 1836 Stephen Allen was anxious to break ground on the Croton Aqueduct. There was a long-felt need for the water it would provide. And it is equally understandable why he was embarrassed over the aqueduct's slow start. Citizens began to doubt that the Croton Aqueduct would ever be completed.

There was strong precedent for such skepticism. Since 1774, about every 20 years a seemingly serious bid had been made to supply New York with water. In 1774 Christopher Colles, an English civil engineer, started to erect a Newcomen pumping engine that would distribute water through bored-log mains.[6] Colles' work was halted by the Revolution. In 1798, after writing that no water on Manhattan was fit to drink, Dr. Joseph Browne initiated a push for a Bronx River aqueduct.[7] His push led to the incorporation of the Manhattan Company, headed by Aaron Burr.[8] But under Burr's brilliant, albeit devilish, leadership, the Manhattan Company promptly gave up any idea it might have had about supplying New York with Bronx River water. It abandoned the expensive Bronx project, and thereby created a "surplus" of capital used to start a bank. While the new bank flourished, the Manhattan Company, to meet the minimum requirements of its charter, half-heartedly provided inferior well water to a limited sector of the city.

Convinced that the Manhattan Company was never going to provide the city with enough water, in 1822 the Common Council and Stephen Allen (then Mayor) revived the idea of a Bronx River aqueduct.[9] Canvass White, an American engineer noted for his important role in building the Erie Canal, conducted instrumental surveys of the Bronx watershed and reported favorably on the plan.[10] Again, the state legislature incorporated a private company to construct a Bronx River aqueduct. But the New York

Water Works Company was short-lived. Its 1825 charter conflicted on the basic issue of water rights with one granted in 1823 to the Sharon Canal Company. Unable to proceed because of this conflict, the Water Works Company never broke ground before surrendering its charter in 1827.[11]

And so it had gone. The Common Council's Committee on Fire and Water had issued report after report on the need for an adequate water supply. Numerous individuals had petitioned the Council for the opportunity to demonstrate proposed solutions to the problem. But all had been to little or no avail. The more outlandish proposals were ignored or quickly struck down. The others were buried by political machinations, legislative bungling, conflicting charters, high costs, the lack of requisite technical skills, or by tiresome debates over whether a water works should be publicly or privately funded.

Belatedly, the debates over private or public funding finally ended. In reaction to the 1828 fire that destroyed $600,000 worth of property, city Alderman Samuel Stevens reported in 1829 that the private institutions chartered to supply the city with water had never fulfilled that goal. The Manhattan Company, for example, had operated for thirty years. Yet it distributed poor well water through unreliable mains only to the lower third of the city, leaving the upper two-thirds without any effective means of fire-fighting. Stevens concluded that, "It has therefore become absolutely necessary for the corporation, in some manner to give the upper part of the city, a supply of water for that purpose."[12] Spurred on by Stevens, the city finally acted on its own. It constructed a $42,000 fire-fighting system, composed of a deep well containing 175,000 gallons, a steam-driven pump, and an elevated reservoir holding an additional 233,000 gallons.

The fire-fighting reservoir demonstrated what the city could do when it quit relying on private enterprise to solve a public problem. After the reservoir's completion, there was increased agitation for the construction of a centralized water system. At the end of 1830, Samuel Stevens again served as a catalyst. He asked the Council to send a memorial to the state legislature that set forth the failures of private enterprise; the memorial would also request that the city itself be empowered to construct a water system.[13]

Because a majority believed that the state legislature would not grant such a request, Common Council voted the memorial down on February 28, 1831. But the vote signified no lack of determination or interest. On the day of this vote, the Council grew even more determined to solve the water problem, after hearing a report from the Lyceum of Natural History on the impurity of the city's water.

The quantitative side of the Lyceum's presentation had its effect. Chemist George Chilton reported that seven water samples from the city contained 4.05 to 10 grains of solid matter per pint, including such "ingredients" as muriates of soda and magnesia; sulfates of magnesia and lime; carbonates of lime and magnesia; and "extractive matter."[14] But the more narrative portions of the report carried the greatest impact: "It has been observed . . . that the vicinity of grave yards communicates a ropy appearance to the water." And: "Into the sand bank, underlying the city, [from where we draw our water] are daily deposited quantities of excrementious matter, which, were it not susceptible of demonstration, would appear almost incredible."

The "excrementious matter" amounted to one hundred tons per day and did not include urine, a substance which, strangely enough, had a beneficial effect on the city's underground water sources:

> This liquid, when stale or putrid, has the remarkable property of precipitating the earthy salts from their solution, or in other words, it makes hard water soft. Although the fastidious may revolt from the use of water thus sweetened to our palate, it is perhaps fortunate that this mixture is daily taking place, for otherwise the water of this city would become, in a much shorter space of time than it actually does, utterly unfit for domestic purposes.

After detailing the poor condition of New York's hard and foul water, the Lyceum explained why New Yorkers tolerated it:

> We must impute to long use and the influence of habit the opinion that our water is sufficiently pure for domestic purposes. We have known our citizens, upon going into the country, [to] express a marked disrelish for pure spring water. The popular expression on such occasions is, "This water is like wind -- there is nothing substantial in it, nothing to bite upon . . ." The coldness of our pump waters is another cause which conceals their impurities when swallowed. This may be tested by allowing it to stand until it has acquired the ordinary summer temperature; its various ingredients become then manifest, palpable.

In concluding, the Lyceum's report deplored any further toleration of poor water. Its writers unanimously opined "that no adequate supply of good or wholesome water can be obtained on this Island, for the wants of a large and rapidly increasing city like New York."[15]

The belief that no Manhattan water was fit to drink was by no means new. Dr. Browne had expressed it in 1798. But, like the concept of public funding, it was an idea whose time had come. On Novemeber 25, 1831 chemist Chilton quantified the difference between water taken from on and off Manhattan. Water drawn from a Manhattan Company pump yielded 125.80 grains of solid matter per gallon; a gallon of Bronx River water yielded less than 2 grains.[16] Armed with this data, in 1831 Samuel Stevens and the Committee on Fire and Water strongly, if unimaginatively, recommended construction of a two-million-dollar Bronx River aqueduct. The committee urged that the Common Council:

> approach the subject as one of vast magnitude and importance to an already numerous and dense population, requiring our municipal authorities no longer to satisfy themselves with speeches, reports, and surveys, but actually to raise the means and strike the spade into the ground, as a commencement of this all important undertaking.[17]

Convinced of the need for action, Common Council submitted a draft bill to Albany that sought authorization for the city to initiate a Bronx River aqueduct. The draft bill called for the creation of a Board of Water Commissioners to administer the work--the Board was to be appointed by the Governor with Senate consent. Previously, the Council had itself intended to oversee the construction of any water works. But that body was marked by political factions, and its members were susceptible to the whims of voters. It was believed that appointed Commissioners would provide the project with more constant and unified leadership.[18]

When the draft bill reached Albany, it was defeated, presumably because of the Legislature's lack of faith in the water wheels that were required at one point to lift the Bronx water into a reservoir 120 feet above tide, before it could be distributed throughout the city. Many legislators seemingly were averse to using machinery as a critical part of any water system that would operate day in and day out.[19] Machinery was costly to construct, prone to serious failure, and needed constant maintenance. Gravity, on the other hand, was both free and reliable. The legislators in Albany were holding out for a proposal whereby gravity would carry water across to Manhattan on a level high enough to obviate pumps.

Actually it was fortunate that the legislature voted down the Bronx River aqueduct. When Dr. Browne first suggested it in 1798 it was a bold plan that promised New York an adequate water supply for years to come. When Canvass White and the New York Water Works Company worked with the idea in the mid-1820's, the plan still seemed viable. But by 1831, even as the Committee on Fire and Water once again recommended going to the Bronx, others had decided that the river was not large enough. Cyrus Swan, President of the New York and Sharon Canal Company, asserted that it was not capable of meeting both the present and future needs of the city. Instead of turning to that old standby, Swan said that New Yorkers should rely on the Croton River.

Cyrus Swan was by no means the first to mention the Croton. In 1824, Canvass White wrote that "the Croton can be taken out at a sufficient elevation, and conducted along the bank of the Hudson River to the city."[20] White dismissed the Croton, though, because he "presumed that a sufficient supply can be had from the Bronx, much nearer, and of course at less expense." The same presumption held with the Fire and Water Committee in its 1831 report. Before recommending the Bronx, the Committee made brief mention of the Croton:

> The advocates of bringing the water from the Croton, base their argument mainly on the abundance of the supply to be obtained from that river. This important advantage must be yielded to the advocates of this plan, over that of all the others; and were it not for the distance which the Croton River lies from the city, it certainly would be the most desirable source whence to procure the supply. 21

City officials and consulting engineers had always dismissed the Croton, saying that it was unnecessarily large or too far from Manhattan. Now, however, when it was apparent that the city had to go off Manhattan for water, and when critics more frequently stated that the Bronx River was too small to provide a long-range supply, the Common Council had to give the Croton more serious consideration. And the river suddenly had one important advantage. Because it ran at a higher elevation than the Bronx, perhaps it could be delivered to the city without the use of pumps.

If the legislative defeat of the Bronx River aqueduct in any way diminished the enthusiasm for a municipally funded water system, the Asiatic cholera epidemic in 1832 quickly rearoused interest. Alderman Myndert Van Schaick, Treasurer of the city's Board of Health, urged action, and on November 10, 1832 the Committee on Fire and Water engaged Colonel DeWitt Clinton, Jr. to conduct yet another investigation of possible water sources. On December 22, Clinton submitted an engineer's report that was an excellent piece of propaganda.[22] He said the city should build a water works immediately, using the Croton River, with a minimum flow of twenty million gallons per day, as a source. "This supply may . . . be considered as inexhaustable, and it is not at all probable that the city will ever require more than it can provide." 23

Clinton did not deal with all the engineering problems to be faced in delivering Croton water onto Manhattan, but he did outline an aqueduct to do the job. Clinton's aqueduct was an open canal with provisions for keeping dirt, debris, and vegetable matter out of the channel. It ran on a high bank alongside the Croton until entering the Hudson Valley, where it began running southward in the margin of that river. All the while it maintained a declivity or downward slope of 18 inches per mile. Eventually, in order to stay on its grade line, the aqueduct left the Hudson, cut inland, and ran to the Harlem River, which it crossed on a bridge 138 feet high. Clinton's plan required no pumping machinery; the proposed aqueduct was high enough to connect directly with reservoirs and distributing pipes.

The consulting engineer estimated that it would cost 2-1/2 million dollars to implement his plan, but he stated that even if it cost 11 million dollars, it would be worth it. The estimate was a shrewd bit of engineering diplomacy, intended to minimize objections that might be raised on the basis of cost. To arrive at such a low estimate, Clinton, of course, had proposed an aqueduct canal, the cheapest to build, even though Canvass White and the Fire and Water Committee had already stated that a canal offered the least protection for the purity of the water under transport. Nevertheless, the consultant had done his job well. In less than a month and a half, and without the aid of instrumental surveys, he projected a feasible and economical plan that encouraged the construction of a water works.

Two days after receiving Clinton's report, the persistent, ever-resilient Fire and Water Committee proposed yet another bill to go to Albany requesting that long-sought authorization to build a water works. But Common Council wisely referred the bill back to committee, because it was too much like others that had failed to pass. Before returning the bill in February 1833, the Committee significantly revised it. Now it sought a more limited but practicable goal. The draft bill again requested the creation of a Bo ard of Water Commissioners, but the Board would not actually build a water system. Instead, it would simply examine various plans, conduct instrumental surveys, and estimate the costs of possible aqueduct routes to Manhattan, especially one from the Croton River.[24]

When this bill reached Albany, a senator sensitive to New York's water problems supported it. Myndert Van Schaick, the former alderman and Board of Health Treasurer, effectively campaigned on behalf of the bill, which the Legislature passed on February 26, 1833.[25] Shortly thereafter Governor William Marcy appointed a Democratic Board of Water Commissioners composed of Stephen Allen, Saul Alley, Benjamin Brown, Charles Dusenburry, and William Fox. The Commissioners, appointed to one year terms, were directed to report their findings to New York's Common Council by the first of November.

The new Water Commissioners selected Stephen Allen as their Chairman and got down to business. In need of consulting engineers, they approached Canvass White, by then a veteran of the city's quest for water, and Major David Douglass, a newcomer to the problem. White accepted the employment, but he was never able to complete his assignment. He was also working on the Raritan and Delaware Canal, and in the summer of 1833 the canal was plagued by floods, so White could not leave it. Consequently, the task of providing the Water Commissioners with technical expertise fell solely to Major Douglass.

David Bates Douglass, the son of Deacon Nathanial and Sarah Douglas[s], was born in Pompton, New Jersey in 1790.[26] After being tutored by the

Reverend Samuel Whelpley in Newark, Douglass entered Yale College as a sophomore. He took prescribed courses in languages, astronomy, chemistry, mathematics, navigation, surveying, and natural philosophy.[27] Douglass graduated in 1813, and on October 1 of that year the Army sent him to West Point for training.

Following a short stint at the Military Academy, the young officer caught up with the War of 1812 on the northern frontier. He commanded a company of Bombardiers, Sappers and Miners and participated in the reconnaissance of Fort George, the Battle of Niagra, and the defense of Fort Erie. The army commended Douglass for his gallant action in defense of the fort, and on January 1, 1815 Brevet Captain Douglass returned to West Point as an Assistant Professor in its new Department of Natural and Experimental Philosophy.

Douglass was the second man in the department. The first, Lieutenant Colonel Jared Mansfield, had just started his instruction the previous April. Together, Mansfield and Douglass instructed the cadets on a broad range of subjects, most of which today would fall under the rubric of "physics."[28] After dealing for five years with topics such as dynamics, statics, and hydraulics, Captain Douglass served for the next three years as a professor of mathematics.[29]

In 1823, following a promotion to Major, Douglass transferred to the Department of Engineering, which was just starting to offer "civil architecture and construction" along with its usual instruction in artillery practices, fortifications, and "Grand Tacticks."[30] Occasionally, Douglass left the Military Academy for forays into the field. In 1817 he reconnoited the defenses of Long Island Sound. In 1819 he served as astronomical surveyor for the commission establishing the United States border between Niagra and Detroit, and in 1820 he accompanied General Lewis Cass on his exploration of the Lake Superior region. After joining the Department of Engineering in 1823, Douglass consulted on public works for the states of Pennsylvania and New York. He also surveyed the routes of the Upper Delaware Canal, the Sandy and Beaver Canal in Ohio, and the Morris Canal in New Jersey.

While Douglass served at West Point, it was the only institution in America that offered a formal engineering education. For the most part, an American engineer learned his profession on the job. A "student," even one with college training in the sciences usually started as an axeman of rodman with a surveying party. He worked his way up from there. Lacking in European-styled polytechnical institutes, American engineers cut their teeth on the public works that proliferated after the completion of the Erie Canal.[31] These projects served as "schools" of engineering, and the Erie Canal, running from Buffalo to Albany, had been the most impressive "school" of them all. The Erie graduated several of America's most prominent engineers in the first half of the 19th century.

Douglass, the Yale graduate and West Point professor, was cognizant of the fact that he was working somewhat outside America's "mainstream" of civil engineering. The exciting, prestigious and lucrative action was not in the classroom, but in the field where engineers were building bridges, canals and the earliest railroads. Douglass was involved in this work only as a consultant, and that was not enough. He wanted to become directly involved in the work-a-day world of civil engineering.

At the same time, he realized that his career at West Point had already peaked. He had been passed over for a choice professorship; he was refused permission to travel to France for further technical training.[32] So in a sense, Douglass was simultaneously lured away and pushed away from West Point. In 1831 he resigned the faculty to become Chief Engineer of the Morris Canal, whose route he had surveyed in the summer of 1828.

Douglass stayed with the Morris Canal for about a year and a half. He improved it by substituting inclined planes for canal locks on long slopes. That job completed, he briefly returned to academe in 1832 as a professor of natural philosophy at New York University. Douglass again found the role of full-time professor too restrictive, so in 1833 he resigned his chair of natural philosophy to accept a more compatible position. The university appointed him a professor of civil engineering, but with the understanding that he would lecture only when and if he wanted.

For Douglass, this was the perfect arrangement. He was still associated with academe, as he had been for virtually all his adult life, but he was also free to undertake any tantalizing engineering field work that came his way. In 1833, while he was surveying the Brooklyn and Jamaica Railroad on Long Island, New York's Water Commissioners asked him to serve as a consultant. Douglass jumped at the chance. It was a move that could lead to an important chief engineership. It was an opportunity to get in on the ground floor of a major public work that could elevate him to the top of his profession.

NOTES -- CHAPTER ONE

1 This summary of the early history of New York's water problem is largely drawn from the following sources: Fayette B. Tower, Illustrations of the Croton Aqueduct (New York, 1843); Charles King, A Memoir of the Construction, Cost and Capacity of the Croton Aqueduct (New York, 1843); Edward Wegmann, The Water Supply of the City of New York (New York, 1896); Nelson Blake, Water for the Cities (Syracuse, 1956); and Charles H. Weidner, Water for a City (New Brunswick, 1974).

2 For a more detailed description of early Manhattan water sources, see George Everett Hill and George E. Waring, Jr., Old Wells and Water-Courses of the Island of Manhattan (New York, 1897).

3 The quote is taken from Weidner, p. 16.

4 Weidner, pp. 17, 18, 28.

5 Lyceum of Natural History, "Report, Feb. 22, 1831,: in In Common Council (New York, February 28, 1831), p. 9.

6 Tower, p. 57; King, p. 85.

7 See Browne's "Memoir of the Utility and Means of Furnishing the City with Water from the River Bronx," in Proceedings of the Corporation of New York, on Supplying the City with Pure and Wholesome Water (New York, 1799).

8 For a much more thorough account of Aaron Burr's Manhattan Company, see Blake, pp. 44-62. Also see Weidner, pp. 20-22; King, pp. 95-99; Tower, p. 58.

9 King, pp. 100-101; Weidner, p. 24; Tower, pp. 58-61.

10 See "Canvass White's Report, January 28, 1824," in Fire and Water Committee, Report to the Board of Aldermen (New York, December 28, 1831); also, Canvass White, Report to the Directors of the New York Water Works Company (New York, 1826).

11 Tower, p. 61; King, p. 103.

12
King, p. 105; also see Wegmann, Water Supply of NY, pp. 16-17; Weidner, pp. 26-27.

13
Weidner, pp. 26-27.

14
For a discussion of the relationship between water purity and public health, see Blake, pp. 248-264.

15
Lyceum of Natural History, pp. 8-10.

16
King, p. 107.

17
Fire and Water Committee, (December 28, 1831), p. 1.

18
Ibid., pp. 12-13.

19
Weidner, p. 27.

20
"Canvass White's Report," p. 20.

21
Fire and Water Committee (December 28, 1831), p. 4.

22
See "Report of Colonel DeWitt Clinton to Committee on Fire and Water, December 22, 1832," in Board of Aldermen Doc. No. 61, pp. 191-245.

23
Quoted in Weidner, p. 29.

24
Blake, pp. 135-136; King, p. 115.

25
Acts of the Legislature of the State and Ordinances and Resolutions of the Common Council . . . in Relation to the Subject of the Introduction, Supply, and Use of Croton Water (New York, 1861), pp. 3-4.

26
This biographical sketch of Douglass is drawn from the following: "Major David Bates Douglass," Van Nostrand's Eclectic Engineering Magazine (January, 1872), pp. 1-6; G.W. Cullum, Biographical Register of

the Officers and Graduates of the U.S. Military Academy (Boston, 1891), I, pp. 35-36; Franklin B. Dexter, Biographical Sketches of the Graduates of Yale College (New Haven, 1912), pp. 550-553.

27
The Laws of Yale College (New Haven, 1811), pp. 15-17.

28
The Centennial History of the U.S. Military Academy (Washington: G.P.O., 1904), pp. 261-263.

Mansfield and Douglass used the following texts: Enfield's Institutes of Natural Philosophy; Parkinson's Mechanics, and Gregory's Treatise of Mechanics. They instructed the cadets in statics, hydrostatics, dynamics, hydrodynamics, heat engines, hydraulics, pneumatics, optics, electricity, magnetism, astronomy and machinery design.

29
Ibid., p. 244.

Douglass used Hutton's Compendium as his main text and lectured on arithmetic, logarithms, algebra, geometry, trigonometry, land surveying, descriptive geometry and conics.

30
Ibid., pp. 276-277. Also see "Studies and Class Books, in Regulations of the U.S. Military Academy at West Point (New York, 1823); and "Highlights of Department History," compiled for the Dept. of Military Art and Engineering, U.S.M.A., by N.E. Derhson, 1960, U.S.M.A. Archives.

The texts used by the Department of Engineering in 1823 were Gay de Vernon's Treatise of the Science of War and Fortification; Hachette's Traite des Machines; and Sganzin's Programme d'un Cours de Construction.

31
Three books that discuss the development of engineering as a profession in the 19th century are David Hovey Calhoun, The American Civil Engineer: Origins and Conflict (Cambridge, 1960); Monte A. Calvert, The Mechanical Engineer in America, 1830-1910 (Baltimore, 1967); and Raymond H. Merritt, Engineering in American Society, 1850-1875 (Lexington, 1969).

32
Douglass seems to have been plagued throughout his career by his inability to get along with superiors. West Point's Thayer, for example, characterized him as "self-centered, ill-tempered; and [tending] to hold a grudge." Thayer to General Swift, May 15, 1855, Thayer Papers, U.S.M.A.

CHAPTER TWO

From the start of his service, Major Douglass ignored several water-supply proposals being bantered about. He ignored the idea of damming the Hudson to prohibit the entrance of salt water; he was oblivious to the die-hards who wanted to sink very deep wells on Manhattan. Douglass concentrated on the feasibility of delivering water from the Croton. Traveling on foot and horseback, in early June 1833 he made a "general reconnaissance" of the Croton watershed and the land lying between the river and Manhattan. Then he collected an eleven-man surveying party at the Croton's mouth. The party started its instrumental survey on June 20 and continued it until September 4. In less than 70 working days, Douglass and his men levelled over 200 miles and traversed more than 3,400 courses.[1]

After establishing the low water level of the Hudson River as their base, or zero, elevation, the men worked their way up the Croton and its branches and feeders, noting elevations at key locations where an aqueduct could conceivably start. After determining the elevations, Douglass next examined the ground south of the Croton "with a view of obtaining practical routes in the direction of the city."[2]

The land the engineer crossed was "deeply undulating," marked by "irregular hills," and he hoped to find an easy valley passage nestled between the slopes. But Douglass quickly discovered that the hills, taken together, "contained the rudiments of a great ridge." The ridge rose substantially higher than his potential starting points for the aqueduct. Douglass dead-ended several times while seeking a passage through the ridge that did not require a prohibitive number of long tunnels or deep excavations. Finally he found what he was looking for. An aqueduct could follow the valleys of several small streams until entering the Sawmill River Valley, which ran southward towards Manhattan. Cutting the ridge to pass from one valley to the next would entail considerable expense, but no cut on the way to the Sawmill River presented insoluble problems.

Cutting the ridge south of the Croton seemed the shortest line to Manhattan, but Douglass anticipated that it was not the only line. Indeed a more "obvious" route had been noted by Canvass White in 1824 and by DeWitt Clinton, Jr. in 1832. Instead of running south to confront the ridge, an aqueduct could skirt it by staying in the Croton's valley and running southwestward until entering the Hudson valley. Then it could run towards Manhattan along the eastern bank of the Hudson. Upon examination, Douglass quickly concluded that the Hudson route presented no "difficulties involving the question of practicability."

With two possible routes in hand, Douglass surveyed southern Westchester County, northern Manhattan, and part of the Bronx River watershed. When the surveys were concluded, he gaged the flow rates of the streams and rivers he had examined. Then on November 1, Douglass reported to the Water Commissioners.

The engineer restricted himself "to a general outline of the facts and principles concerned--avoiding, as far as possible, all details not strictly necessary for the elucidation of the main question." As to the feasibility of a Croton Aqueduct, Douglass answered with an unequivocal "Yes." He described how a masonry conduit could follow either of the two routes discovered by his party.

An aqueduct taking the "inland route" would be a complicated affair.[3] It needed all the elevation it could get before confronting the ridge, so Douglass started it at a natural basin of solid rock located high above the Croton at Mechanicsville. At Mechanicsville the Croton's elevation was 170 feet; the basin's was 268 feet. Obviously, Douglass could not fill the basin with water drawn directly from the river below, unless he used pumps, and he did not want to do that. To fill the basin, or "confluent reservoir," Douglass suggested running large iron pipes out and up to the Croton's branches and feeders. The pipes would intersect the feeders at points higher than 268 feet. Water ponded behind small dams would be diverted into the pipes and conducted, under pressure, to the confluent reservoir.

Starting from the basin, the free-flowing masonry aqueduct ran with a declivity or downward slope of only one foot per mile. It sacrificed little elevation until passing the ridge. It ran successively within the Beaver Dam River, Muddy Brook and Newcastle valleys. Then it passed through a man-made cut some 38 feet deep and three miles long. It entered the Sawmill River valley and started to run with an increased declivity of six feet per mile in order to conform better to natural terrain. After leaving the Sawmill and entering the valley of Tibbets Brook, the inland aqueduct ran with a fall of two feet per mile all the way to the Harlem River.

Because the inland aqueduct's declivity varied considerably, the masonry conduit's interior dimensions also had to vary to achieve a uniform flow rate. Water running down a steeper slope would travel with greater velocity, so Douglass sent it through a smaller conduit. Conversely, where he reduced the declivity, he had to increase the conduit's cross-sectional area.

The engineer's aqueduct routed along the Hudson was much simpler.[4] A 13-foot dam on the Croton near Muscoot Hill backed up the water and created an 80 acre reservoir. Starting at an elevation of 175 feet, the aqueduct ran with a declivity of 15 inches per mile all the way to Manhattan. The line, until passing south of Tarrytown, was "wholly traced along the undulating hill-side of the Croton and Hudson" valleys. Where the high ground next to the Hudson began falling away, the aqueduct cut inland to find ground better suited to its established grade. The Hudson-routed aqueduct, like the inland aqueduct, eventually found its way to the Harlem River via the Sawmill River and Tibbets Brook valleys.

From the Harlem River into Manhattan, Douglass proposed only one line. Regardless of how it got to the Harlem, his aqueduct crossed the river on a masonry bridge of unprecedented size in American. This bridge was to stretch 1188 feet and stand some 126 feet above the river. Although he had absolutely no experience in engineering such a structure, Douglass shrugged off its difficulties. His report exhibited an optimism common among early American engineers:

> Our structure adapted to these dimensions would of course be a work of considerable labor and expense, but by no means of paramount difficulty in either of these respects. Many bridges of much greater magnitude, both in length and height, have been erected in other countries for the same object, from which we are enabled to derive certain data for all calculations. . .

> With such examples of enterprise and skill before us, many of them undertaken for objects far less important than that of supplying the city of New-York with water, we may certainly look upon the design of the Harlem aqueduct without fear.[5]

From the Harlem bridge, Douglass ran the aqueduct to a receiving reservoir and then through two equalizing reservoirs. Its terminus was a distributing reservoir located near 38th Street and Fifth Avenue. The distributing reservoir would provide a head to the city's future water mains of 117 feet above tide.

Douglass' inland aqueduct ran 43 miles. Its estimated cost varied from 4.5 to 5.8 million dollars; the cost depended on how many iron pipes the city might choose to lay between the Croton's feeders and the confluent reservoir at Mechanicsville. For 4.5 million dollars, Douglass expected a minimum daily delivery to Manhattan of 15.8 million Imperial gallons. For an additional 1.3 million dollars, he could boost the minimum to 26 million gallons.[6] Regardless of the selected minimum, the inland aqueduct was designed to deliver a maximum of 30 million gallons.

The Hudson-routed aqueduct ran 47 miles. After making "every calculation. . .on the side of stability and permanency," Douglass estimated the aqueduct would cost 4.7 million dollars and provide a daily running supply of up to 33 million gallons. According to Douglass, there would be no difficulty in providing the full amount, because the minimum daily flow of the Croton was 44 million gallons.

Douglass did not choose between the two routes. Such a preference, he said, would have to await future examinations. And Douglass did not really argue the supremacy of a Croton aqueduct over one from the Bronx

River. He simply stated some figures and left it at that. According to research undertaken by the Water Commissioners, London distributed 27 gallons of water per day to each citizen, while Philadelphia distributed 24 gallons and Edinburgh about 15. On an average, then, water works in large cities distributed about 22 gallons per day per person.[7] New York's population would be 300,000 by the time an aqueduct could open, so it would have to deliver at least 6.6 million gallons daily to meet the city's immediate needs. After gaging the Bronx, Douglass concluded that New York could "safely" depend on it for only 5.75 million gallons.[8] That figure closed the book on any Bronx River aqueduct, and it laid to rest a frustrating 35-year long debate over the merits of such a project.

The Water Commissioners digested Douglass' report favoring the Croton, and on November 12, 1833 they presented a concurring report to the Common Council. Early in 1834 the Council asked Albany for the authority to raise 2.5 million dollars to begin a water works, and Senator Myndert Van Schaick again guided the water-works bill through the legislature. On May 2, 1834 the legislature passed an act directing the reappointed Water Commissioners:

> to examine and consider all matters relative to supplying the city of New-York with a sufficient quantity of pure and wholesome water; [and] to adopt such a plan as in their opinion will be most advantageous.[9]

Under the act's provisions, the Commissioners were to re-examine their previous work. But they were to go beyond just another study. They were to adopt a plan that would go first to New York's Common Council. If approved there, it would go to the next general election.

If the city's voters endorsed the plan, then the city could issue 2.5 million dollars worth of Water Stock, and the Commissioners could begin the work.

In pursuit of an acceptable plan, the Commissioners asked Major Douglass to "re-examine his surveys, levels, and calculations." Perhaps he could devise a Croton aqueduct that would entail "less labor and expense."[10] Initially the Commissioners, like Douglass, had made no choice between the inland the Hudson routes, but by now they preferred the Hudson route "both as to the practicability and expense of its construction."[11] So they instructed Douglass to try to shorten and improve that line.

As a check upon Douglass' work, the Board also enlisted the services of John Martineau, a veteran canal builder, and George Cartwright, a Westchester engineer familiar with the Croton environs. These men worked independently, and the task that confronted each man was best summarized by another engineer:

> It was a field for the exercise of the talent and research of the engineer: in resorting to a distant stream for a supply, any plan which he might propose for conveying the water, would encounter obstacles requiring skill and ingenuity to overcome. He would find it necessary to build up the valleys, pierce through the hills, and span the waters of the arms of the sea which embrace the city and make it an island. Structures would be required, which in their design, would find no parallel among the public works of this country.[12]

On October 21 Major Douglass took an eight-man party into the field. They started work at the Croton and suffered much cold weather before concluding on Manhattan on December 13. For the next month and a half, Douglass evaluated the field data and applied hydraulic, structural and economic criteria to discriminate between the various means of carrying a Croton aqueduct along the Hudson River to Manhattan. On February 1, 1835, he submitted his second report to the Water Commissioners.[13]

The Hudson-routed aqueduct that Douglass reported in 1835 differed considerably from its predecessor. In his 1833 report he located a dam just above Muscoot Rapids, 11 miles from the Croton's mouth, where the river was "compressed into a narrow channel" and "bounded on either side by bold shores." Here the river's bed stood 163 feet above tide, so a dam only 13 feet tall would raise the Croton to 175 feet. From this elevation, the aqueduct could run with a declivity of 15 inches per mile all the way to Manhattan.[14] But after his second examination, Douglass chose not to use the Muscoot Rapids site. He moved the dam 5 1/2 miles downstream to just below Garretson's Mill.

The downstream site seemed naturally suited for a dam; the Croton contracted and ran between a stone bluff and a steep hill. By moving the dam, which shortened the aqueduct by 5 1/2 miles, Douglass anticipated a savings of $92,000.[15] But to gain this savings, he had to sacrifice some elevation-- a commodity very valuable in its own right.

Between Muscoot Rapids and Garretson's Mill the Croton descended about 38 feet. To fully regain this lost elevation, Douglass would have had to specify the construction of a dam about 45 feet tall at Garretson's Mill, and he did not want to do that for two reasons.

First, he though a 45-foot dam would be exceedingly expensive and difficult to construct. Secondly, it would flood too much property on its upstream side and increase the cost of land acquisition for a fountain reservoir. So Douglass opted for a dam 33 feet tall, and he settled for a reduced elevation of 155 1/2 feet for the aqueduct's start. Since he sacrificed starting elevation, he reduced the aqueduct's declivity and increased the conduits interior dimensions. The aqueduct starting at Garretson's Mill ran downward at a rate of 12, not 15, inches per mile.

After relocating the dam, Douglass adjusted the aqueduct's line in Westchester County to accommodate its new grade. From the dam to below Tarrytown these adjustments were minor. The aqueduct traversed the same slopes, but it ran lower in the Croton and Hudson valleys. Only near Greensburg did the engineer note the first significant change in the line.

In his 1833 report the aqueduct left the Hudson at Greensburg and passed through a deep cut to enter the Sawmill River valley. But Douglass now though it too expensive to make this cut, which would have to be much deeper because of the aqueduct's reduced elevation. He carried the line further south along the Hudson and routed it into the Sawmill's valley at Yonkers. From the Sawmill the aqueduct passed along the valley of Tibbets Brook and crossed Bathgate's Meadow to reach the Harlem River. By the time it reached the Harlem, the 1835 line virtually coincided with the 1833 line, and Douglass once again recommended a high bridge to carry the aqueduct over to Manhattan.

Once on the island, instead of sending the aqueduct through four reservoirs, he sent it to a single less expensive distributing reservoir tentatively located on Murray Hill (between Fifth and Sixth Avenues and 38th and 42 Streets). The water in the reservoir would stand 114 feet 10 inches above tide, making the reservoir "competent to deliver the water, without any extraneous aid, upon the roof of every building in the city."[16]

After delineating the aqueduct's route, Douglass outlined its physical characteristics, paying particular attention to the water-carrying channel. The channel had to be permanent, yet, as the Commissioners emphasized, as economical as possible. It also had to protect the purity of the Croton's water, which contained only 4.16 grains of solid matter per gallon.[17] Working with these criteria, Douglass narrowed down his options.

He dismissed a canal-like channel because it jeopardized the purity of the water and offered no protection from frost. He abandoned the idea of using iron pipes, because he feared their initial expense and doubted their durability.[18] Next Douglass turned to a channel lined with masonry and covered with a wooden roof. This conduit was structurally sound; its inclined sides of brick and stone rested safely on earthen banks. And the shape of the conduit, with its slanting sides and rounded bottom, lent itself well to "self cleaning." The water would scour the bottom and keep it free of sediment.

This design's greatest asset was its relatively low estimated cost of $43,630 per mile. The conduit offered minimal protection from frost, and its wooden roof lacked permanence, but Douglass felt that for the sake of economy the Water Commissioners could adopt this construction on as many as 28 miles of the line. Still, there was a better way to construct the channel--by making it a totally enclosed masonry conduit. Except for its high initial cost, estimates at $62,000 per mile, Douglass believed the enclosed channel of brick and stone "was preferable to every other."[19]

In choosing a "horse-shoe" cross-section for the enclosed conduit, Douglass struck a compromise between hydraulic principles and the realities of construction. Engineers knew that a cylindrical conduit was the most efficient for carrying water. The water passing through any channel is slowed by friction as it contacts the walls, or the channel's "wetted perimeter." The cylindrical conduit is the most efficient, because for any given cross-sectional area it maintains a smaller "wetted perimeter" than other geometric shapes. Yet despite their knowledge of this principle, engineers rarely constructed power or transportation canals or other hydraulic works in strict accordance with it. Instead, they generally adopted a cross-section that resembled a circle, but was less expensive, easier to construct, and in some instances, more stable when put in the ground:

> The circle presents the best surface, and is therefore the most suitable for the conveyance of water, and the nearer we come to . . .a circle in the formation of the cross-section, the least resistence will the water meet with its flow.[20]

Douglass' "horse-shoe" indeed mimicked a circle. The bottom was part of a circle, an inverted arch. Then, in imitation of a circle rising up and outward from its lowest point, Douglass planned for flat side walls that sloped outward as they rose from each end of the inverted arch. Over the bottom and sides, which would carry most of the water, the engineer proposed a semi-circular top arch. Compared with a circular cross-section, the "horse-shoe" was slightly less efficient, but its flat sides were simpler to construct, the overall shape was easier for men to move and work in, and it provided, Douglass felt, "the greatest degree of strength and stability, with the smallest amount of material."[21]

Taken as a whole, Douglass' second report was more thorough than his first, but it was not complete or definitive. The engineer did not describe any of the aqueduct's structures--its dam, reservoir, conduit, bridges, culverts, or embankments--in sufficient detail to guide any future contractors in their work. And when Douglass' report was taken with Martineau's, or with Cartwright's brief report, the proposed aqueduct became even less distinct.

The engineers differed on point after point. While Douglass suggested a 33-foot dam at Garretson's Mill, Cartwright leaned towards a 40-foot dam at the mill, and Martineau, determined to shorten the aqueduct as much as possible, opted for a 150-foot dam just a mile upstream of the Croton's mouth.[22] Douglass proposed a "horse-shoe" conduit, while Martineau, following hydraulic principle to the letter, proposed a cylindrical conduit, and Cartwright an open canal. Douglass' aqueduct would deliver 30 million gallons of water per day. Martineau's would deliver 40, and Cartwright's only 20.

Douglass would cross deep valleys with aqueduct bridges, while Martineau preferred massive embankments. Douglass retained his high masonry bridge across the Harlem River; Martineau recommended crossing the river with a low structure carrying an "inverted syphon" of wrought iron pipes.[23] The Douglass aqueduct ran 41 miles and would cost an estimated 4.8 million dollars, if the enclosed conduit were used exclusively. Martineau's ran 36 miles at a cost of 4 million dollars. But despite all these differences, the engineers agreed on the essential point: New York could build a Croton aqueduct in the margin of the Hudson River.

The Water Commissioners, when they reviewed the engineers' reports, were undisturbed by the variant plans. Perhaps they were even pleased that their resourceful consultants presented them with such an assortment of means to accomplish the same end. At any rate, on February 16, 1835 the Commissioners reported to Common Council their own plan for a Croton aqueduct that would cost an estimated 4.25 million dollars. The Commissioners proposed:

> that a dam of sufficient elevation be erected near the mouth of the Croton River, and from thence the water to be conducted in a close[d] stone aqueduct to Harlem River. The river to be crossed by inverted syphons of wrought iron pipes of 8 feet in diameter, formed in the manner that steam boilers are. From the south side of the river, a line of stone aqueduct will again commence, and proceed across Manhattan Valley to the distributing reservoir at Murray's Hill.[24]

The "plan" was none too specific, but it successfully presented the Croton aqueduct as a simple and straight-forward exercise in civil engineering. Common Council approved the plan, and in the next general election, held April 14-16, New York City's voters supported it by a three-to-one margin. With that final endorsement in hand, early in May the Common Council instructed the Water Commissioners to get on with the work.

The Commissioners immediately began searching for a Chief Engineer for the Croton Aqueduct, and on June 2 they unanimously chose Major Douglass at an annual salary of $5,000. The Commissioners and Douglass began with the highest expectations. The Water Commissioners expected their seasoned engineer to carry the work to a prompt completion. Douglass expected the Croton project to shoot him to the top of his profession, while paying him a handsome salary for a number of years.

Before hiring Douglass, the Commissioners had already fleshed out parts of the skeletal aqueduct plan written up in February. They decided that Croton Dam should be 40 feet tall and located a short way downstream of Garretson's Mill.[25] They also wanted a receiving reservoir north of the single distributing reservoir that Douglss specified in his 1835 report. After informing their new Chief Engineer of these decisions, the Commissioners instructed him to "select a proper Corps of assistants at as early a day as possible." Douglass accordingly requested an engineering corps of 17 men: 5 assistant engineers, 5 rodmen, and 7 chainmen and laborers.[26] With only about a third of these positions filled, the new Chief Engineer and his party hurried up to the Croton on June 6.[27]

The first order of business was to identify the land the aqueduct would occupy, so Douglass' corps staked out the boundaries of the fountain reservoir to be formed behind Croton dam. The Commissioners hired George Cartwright to assist in this work by surveying the reservoir and preparing its land maps.[28] After staking the fountain reservoir, Douglass moved back to Manhattan to stake out the reservoirs there. Then he and his men returned to Westchester to run the aqueduct's line from the dam down to the Harlem River--a line predicated on a 40-foot dam and a declivity of a little over 13 inches per mile. Cartwright presented the Commissioners with his land maps of the fountain reservoir in November, while Douglass still worked the line. Finally, by January 8 the corps had staked the line all the way to the Harlem, and Douglass abandoned field work for the rest of the winter.

Set up in New York, Douglass retained eight assistants to conduct office work needed in advance of the next summer's field operations. Their foremost task was to prepare maps showing what land had to be purcheased, and who owned it. The engineering corps also started to develop a general schema for embankments, tunnels and excavations, and more particularized plans for larger structures such as Croton Dam and the high bridge over the Harlem. Because the Water Commissioners now wanted a larger aqueduct, Douglass worked on the cross-section of a new conduit to deliver 45 to 50 million Imperial gallons daily.[29]

The office work proceeded slowly.[30] When winter closed, the engineers had not finished the land maps or any final plans. The Commissioners were dismayed by this "lack of energy in the operations of their Engineer department," and their dismay was nothing new.[31] Their high expectations had already faded. Long before the winter ended, the Commissioners, and particularly Stephen Allen, were at odds with the Chief Engineer.

The friction between Allen and Douglass resulted from a variety of factors. A politician and an engineer were not above a personal squabble. To an extent their falling out reflected the fact that two strong-willed, proud individuals were seeking prestige and credit for executing the same work. Allen felt that Douglass, with two feasibility studies behind him, should have proceeded more quickly in 1835. Douglass, on the other hand, considered the earlier studies as mere preliminaries, every point of which he had to carefully review.

The real conflict, however, resided in their opposing views of the proper working relationship between the engineers and the Board. Douglass believed that his corps should be virtually autonomous, and that he should decide all technical matters. Allen felt that if Douglass exercised such authority, then the Commissioners would be "deprived . . . of nearly all the powers given them by the act under which they were appointed."[32]

This basic conflict arose almost simultaneously with Douglass' appointment. In his last feasibility study, he had opted for a 33-foot dam just below Carretson's Mill; the Commissioners instructed him to construct a 40-foot dam a little further downstream. The Water Commissioners, not Douglass, brought in Ceorge Cartwright to prepare land maps of the fountain reservoir. Douglass continued to plan for a high bridge across the Harlem, while the Commissioners endorsed Martineau's idea of an inverted syphon. Douglass protested each time the Commissioners intervened in the affairs of his engineers, and with each protest, Stephen Allen grew more weary of the Chief Engineer's recalcitrance. It was a situation that grew worse over time, as the two men played a serious game of testing the mettle and resolve of the other.

Stephen Allen had hoped to let some contracts on the aqueduct in 1835. Since the Chief Engineer had failed to complete the land maps over the winter, he began to fear that no contracts would be let even in 1836. Knowing how anxious Allen was to put the line under contract, Douglass tried to manipulate that anxiety. He tried to get Allen to recognize that only a strong and well-manned engineering corps could quickly dispatch the work.

On March 12, 1836 the Chief Engineer requested 60 to 70 men for the summer, including Major Thomas B. Brown, who was to serve as principal assistant engineer at an annual salary of $3,500.[33] This request was extravagant, even for a project of the aqueduct's size and importance. The Water Commissioners immediately denied it, and Allen no doubt hoped that the denial would prompt the Chief Engineer to resign--but he did not.

On March 15, Douglass proposed more modest corps. The Commissioners delayed their approval until April 9--and still Douglass did not resign. So on April 11 a dogged Chief Engineer took to the field with a party that numbered, in different months, from about 13 to 21.

Douglass returned to Westchester County and began his fourth survey of the aqueduct's line. Allen questioned this repetitive work, and Douglass answered that he was still seeking to shorten and improve the route. He also said, according to Allen, that "It would be a great advantage to the work, if every one of the engineers employed, did instrumentally make a level and survey of the line."[34] The Commissioners' chairman knew that most engineers learned their profession on the job. Nevertheless, Allen felt this was no time for training exercises. He wanted nothing to do with neophytes. He wanted land maps, specifications, contracts, and construction.

Allen finally received some land maps on June 11, and on June 17 Douglass provided the remainder. But for Allen, this was a case of getting too little too late. If the Chief Engineer would not resign, then the Commissioners had to establish proper grounds for firing him. They quickly set this up. On June 23 they passed a resolution requiring Douglass to furnish them with:

> plans and specifications of the Croton Aqueduct, the several tunnels along the line of the aqueduct, the embankments on said line, culverts, the Croton Dam, the Aqueduct Bridge over Sing Sing Kill and across Harlem River, with proper descriptions of materials to be used, the manner in which they would be worked together, and all necessary information to enable the commissioners to place a part or whole of the work under contract with as little delay as possible.[35]

Major Douglass acknowledged receipt of the resolution on July 26, but he sent no plans or specifications. On September 13, instead of sending plans, he again requested that Major Brown be hired as his principal assistant. If Douglass stalled in a final attempt to impress the Commissioners with the need for a stronger, larger engineering corps, the ploy failed miserably and played right into their hands. The Commissioners did not believe Douglass was short-handed. They believed he had proved himself incompetent:

> The conclusion was irresistible, and it was unanimous with the commissioners, that Mr. Douglass doubted his own ability to perform the duty required of him in preparing the necessary specifications. . . of the work.[36]

Long before September 1836, Stephen Allen had reached another conclusion: that the Board had hired the wrong type of civil engineer. They had hired "a mere theorist in engineering."[37] In 1840, in a published letter Allen more fully expressed this conviction:

> I have always admitted, that Mr. Douglass was a ripe scholar, a good mathematician, <u>and in theory</u>, well acquainted with the science of engineering. . . .But my opinion, nevertheless, was and still is, that he does not possess that practical knowledge which I deemed necessary to carry on a work of so much importance to the City. . ., and holding these opinions, I should have been traitor to the trust reposed in me, if I had not urged upon the commissioners, the necessity of a change in the office of the Chief Engineer.[38]

Douglass, the Yale graduate, the professor at the Military Academy and at New York University, was a man steeped in engineering literature, and a man practically devoid of any first-hand experience in administering the design and construction of a large public work. He had never carried a major project through from start to finish. Most of his experience had been as a consultant or surveyor. Aside from his inclined planes on the Morris Canal, Douglass, to our knowledge, had never built anything of note. Also, Douglass had been hampered by entering the profession too near the top. By moving laterally from professorships into engineering, he had bypassed some valuable practical lessons. Because of his inexperience, he failed to meet the exacting demands placed upon a chief engineer.

The Commissioners fired Douglass on October 11, after already hiring his successor. Following his dismissal until he died in 1849, Douglass wandered in and out of several positions. Ultimately he became known not as a great engineer, but as a capable designer of cemeteries.

In 1840, Stephen Allen's Water Commissioners were themselves removed from the Croton project, by a Whig governor who appointed a Whig board. At this time Major Douglass attempted to regain the Chief Engineership. In defense of his failure to put the Croton Aqueduct promptly under contract, he recited how the first Commissioners had refused him a strong engineering corps.[39] This defense garnered some support for Douglass, but it was not a strong one. His successor had already destroyed this alibi four years earlier in a six-month flurry of engineering activity.

In September of 1836, Douglass had a corps of 21 men: 5 assistant engineers, 2 draftsmen, 2 levellers, 7 rodmen and 5 axemen.[40] When his successor took over on October 20 he did not augment the staff. On the contrary, when winter arrived and field work ceased, he laid off two-thirds of the men. Yet by the beginning of spring 1837, the successor, "an energetic and practicable Engineer,"[41] had prepared the structural plans and specifications needed to put the head of Croton Aqueduct under contract. The successor was John Bloomfield Jervis, Civil Engineer.

NOTES--CHAPTER TWO

[1]Douglass' work in 1833 for the Water Commissioners is described in his "Engineer's Report," included in "Report of the Commissioners Under and Act of the Legislature of this State, Passed February 26, 1833, Relative to Supplying the City of New-York with Pure and Wholesome Water," Board of Aldermen Document No. 36 (New York, November 1833), pp. 381-408.

[2]Ibid., pp. 381-382.

[3]Ibid., pp. 386-397.

[4]Ibid., pp. 397-401.

[5]Ibid., pp. 394.

[6]Ibid., pp. 397, 401.

[7]Ibid., pp. 365-366.

[8]Ibid., pp. 403, 407.

[9]The full text of the may 2, 1834 act is found in Acts of the Legislature, pp. 5-11.

[10]"Report of the Commissioners Under and Act of the Legislature of this State, Passed May 2, 1834, Relative to Supplying the City of New-York with Pure and Wholesome Water," Board of Aldermen Document No. 44 (New York, February 1835), p. 325.

[11]Stephen Allen, "New York Water Works No. 1," MS, Stephen Allen Papers, New York Historical Society.

[12]Tower, p. 69.

[13]See "Report of Mr. D. B. Douglass," Doc. No. 44, pp. 403-433.

[14]In Doc. No. 36, Douglass called for a 13-foot dam; in Doc. No. 44 he refers to the dam as being 14 feet tall.

[15]Doc. No. 44, pp. 404-407.

[16]Ibid., pp. 414-415.

[17]"Mr. Chilton's Report," Doc. No. 36, pp. 409-410.

[18]Doc. No. 44, note, pp. 421-422. Also see Doc. No. 36, pp. 402-404.

[19]Doc. No. 44, pp. 424-429.

[20]Ibid., p. 358. The quote is from Albert Stein, a civil engineer who apparently volunteered technical assistance to the Commissioners.

[21]Ibid., p. 427. For a discussion of the horse-shoe cross-section, see Edward Wegmann, Conveyance and Distribution of Water for Water Supply (New York, 1918), p. 242.

[22]Doc. No. 44, pp. 360-361, 483-486.

[23]Ibid., p. 496.

[24]Ibid., p. 366.

[25]Allen, "New York Water Works No. 1."

[26]Allen, "New York Water Works No. 1" Also Board of Aldermen Document No. 12 (New York, August 1, 1836), p. 63.

[27]For Douglass' version of his efforts as Chief Engineer, see his letter in the New York Times & Star, October 30, 1840. Also found in New York Courier and Enquirer, October 28, 1840.

[28]Doc. No. 12, p. 63.

[29] F. B. Jervis to John Jervis, March 25, 1836, Jervis Papers.

[30]In February Douglass temporarily put other tasks aside to answer an inquiry from the Mayor regarding "the practicability and expense of raising water from the North [Hudson] or East River by steam power, and delivering it into the contemplated reservoir on Murray's Hill." Ass soon as Douglass could finish the reservoir, the Mayor wanted to store local river water in it for fighting fires. This practice would be temporary, lasting only until Croton water filled the reservoir.

Douglass sympathized with the Mayor's request. In December, when he was still staking the line for the long overdue aqueduct, New York had suffered the worst fire in its history. The fire levelled 20 blocks in the commercial district and put thousands out of work. But sympathetic or not, the Chief Engineer discouraged the idea. First, he could not complete the Murray Hill reservoir much ahead of the rest of the line. Secondly, it would be a mistake to run corrosive salt water through any cast iron pipes later to be used to distribute Croton water.

See Board of Aldermen Doc. No. 24 (New York, February 15, 1836), p. 467.

[31]Board of Assistant Aldermen Document No. 24 (New York, January 9, 1837), p. 103.

[32]Allen, "New York Water Works No. 1."

[33]Douglass, Times & Star, October 30, 1840.

[34]Allen, "New York Water Works No. 1."

[35] John Travis, ed., "Memoirs of Stephen Allen," p. 159. Typescript located in New York Historical Society and in Manuscript Division, New York Public Library.

[36] Stephen Allen, letter, New York Morning Courier and Enquirer, November 12, 1840.

[37] Allen, "New York Water Works No. 1."

[38] Allen, Morning Courier and Enquirer, November 12, 1840.

[39] Douglass, Times & Star, October 30, 1840.

[40] "Schedule of Pay," September, 1836, Jervis Papers.

[41] Allen, Morning Courier and Enquirer, November 12, 1840.

CHAPTER THREE

In September, 1836 Stephen Allen and Saul Alley visited John Jervis in Albany ,where he was working on the enlargement of the Erie Canal. Ready to oust Major Douglass, they asked Jervis to become Chief Engineer of the Croton Aqueduct. Jervis later wrote that he was "quite surprised at receiving the proposition," which he accepted because he saw "no impropriety in accepting a position that appeared professionally desirable and [had been] offered without the least effort or knowledge" on his part.[1] Yet Jervis could not have been too surprised by the Commissioners' offer. For over nine months he had known of Douglass' shaky hold on his position.

The first inkling of Douglass' fall from grace came to John Jervis from Stephen Allen. Toward the end of 1835, Allen asked Jervis for copies of specifications and contracts he had written for canals in New York State. Allen said he wanted to study these documents to see if they were in any way applicable to the Croton Aqueduct.[2] But Jervis took Allen's communication as a sign that Douglass had performed his duties unsatisfactorily. There was no other reason for Allen to have consulted an outsider about specifications and contracts, which were clearly the responsibilities of the incumbent Chief Engineer.

Between January and March of 1836, Senator Myndert Van Schaick sent Jervis a stronger signal of the trouble brewing between Douglass and the Commissioners. Van Schaick, the influential supporter of the legislation that created the Board of Water

Commissioners, invited Jervis to New York to examine plans for the aqueduct. He also expressed the desire that Jervis become professionally involved, perhaps as Chief Engineer.

It is not clear today, and it may not have been clear to Jervis, if Van Schaick contacted him strictly on his own, or if he spoke as a liason sanctioned by Stephen Allen.[3] In either case, men closely associated with the Croton Aqueduct had contacted Jervis twice, and both contacts pointed to serious problems within the engineering corps. His curiosity aroused, John Jervis investigated the situation, using a convenient and reliable informant. His younger brother, F.B. Jervis, worked on the aqueduct. When Jervis sent Allen the requested documents on state canals, Allen had reciprocated the favor by placing F.B. Jervis in a position under Douglass.[4]

On January 27, 1836 F.B. Jervis wrote his brother that progress was being made, "though very slow[ly], in getting ready for contracts on the water works. When the plans are developed, I shall advise you in relation to their character." On February 16 he wrote that "We are going on quite slowly with our office work," and he added that "I have through the politeness of Maj. Douglass obtained a copy of the most important documents published in relation to the N.Y. Water Works, which I will send you by first opportunity." Then on March 25, apparently in response to a specific query from John Jervis, F.B. Jervis wrote:

> I do not know that it would be practicable for me to give you an accurate view of the difficulties existing between Maj. Douglass and the Water Commissioners. I have formed the opinion that the Commissioners, and especially Mr. Allen, wish to so arrange the work so that the credit of its successful prosecution will fall exclusively to them . . . The Board have been almost continually

> passing Resolutions for the last two or three weeks, the general tenour of which go to show in some form that the Board have little confidence in the Engineer. In my opinion, he should resign at once. 5

So before Allen and Alley called on him in September, John Jervis was familiar with the history of the Croton Aqueduct and with the progress, or lack of progress, in its planning. He also knew that a new Chief Engineer was a virtual certainty. Yet there is no evidence that Jervis in any way conspired with Allen for Douglass' removal in order to further his own career. Stephen Allen may have schemed for Douglass' removal on both personal and professional grounds, but there is no evidence that Jervis had any active part in this. If he exacerbated the falling out of Allen and Douglass in any way, it was only by his proximity and stature. Jervis was close at hand, and he was a better, more-experienced engineer than Douglass -- and Jervis could hardly be faulted for that.

John Jervis had a nimble, inquisitive mind. A small man, whatever he lacked in size he more than made up for in energy and perseverance. Judged by modern standards, he was perhaps a "workaholic." He lived for his profession, subordinating his private life to his professional one. Engineering, to Jervis, was more than a bread-winning occupation; it was a demanding way of life imbued with heavy responsibilities. And yet his entrance into the profession had been quite by accident. 6

Jervis was born in Huntington, Long Island on December 14, 1795. In 1798 Timothy and Phebe Jervis moved their family to Rome, a small community in heavily-timbered upstate New York. Raised in Rome, John Jervis endured the hardships of a pioneer. The boy undoubtedly learned a great deal from his father. Timothy Jervis was trained as a carpenter but in Rome he farmed and ran a sawmill. While John Jervis worked beside his father to clear land, cut timber, and run logs through the mill, he gained a practical knowledge of labor, materials and mechanics that would be of much use later in life. Jervis never underestimated the value of the hard toil he had undertaken in Rome's rugged environment. Later, when in a position to hire young men aspiring to become civil engineers, he displayed a preference for aspirants raised in the country. He preferred the sons of farmers over the sons of "influential men in the city."[7]

Timothy and Phebe Jervis belonged to Rome's Congregational Church, which was aligned with Calvinist theology. The parents saw to it that their seven children received a proper Christian upbringing. John Jervis read his Bible and New England primer. He developed a life-long interest in man's relationship to his God that went far beyond any intellectual or spiritual curiosity. He integrated his religion, his life and his work. Jervis trusted in God, but he believed that a "proper trust in God does not exclude the means God has provided for our use. It rather inculcates prudence and energy in conforming to . . . His Commands."[8] His religion freed him to strive for success, but all the while John Jervis tried to act in a moral and sober manner. When he was 81 years old and wrote on the attributes of a good engineer, he made apparent the influence of his moral philosophy:

> A true engineer, first of all, considers his duties as a trust, and directs his whole energies to discharge the trust with all the solemnity of a judge on the bench. He is so immersed in his profession, that he has no occasion to seek other sources of amusements, and is therefore always at his post. 9

His common schooling ended at age 15, and as John Jervis grew to adulthood, he looked forward to a life much like his father's. He toyed with learning Latin; he contemplated various careers. But at age 22 he was still working the farm and sawmill. As it turned out, that was the perfect place for him to be at the time.

In 1817 Judge Benjamin Wright, a family friend, stopped by the house to ask Timothy Jervis for the use of a few of his men. Wright himself had been at the right place at the right time. A country surveyor from Rome, he had been pressed into service as a Chief Engineer on the Erie Canal. The canal was just getting started, and Wright needed men to clear timber for a surveying party. So axe in hand, John Jervis went off to work on the Erie. Eight years later, when he left the canal, he was one of the foremost graduates of its "school" of engineering.

Jervis' rise from axeman to engineer was meteoric. In the summer of 1817 he cleared timber and cut pegs for the surveyors. In the summer of 1818 he served as a rodman. Later that year, he became one of the "men using the instruments," and conducted levels. During the winter he served as a stone-weigher between Onandaga and Syracuse, and the following summer Benjamin Wright named him resident engineer of the 17-mile stretch of canal running from Canastota to Limestone Creek.

In truth, John Jervis was no engineer by 1819, but at least for the first time he had the title. That was one fortunate aspect of the Erie project -- there were so few qualified civil engineers in America that a hard-working inquisitive beginner, quick to learn, was also quick to be given greater responsibilities. These responsibilities presented new problems to solve, new knowledge to be acquired, and new opportunities for advancement. As long as a young, ambitious prospect did not falter, his upward mobility was almost assured.

By the time Jervis left the Erie in 1825, he had indeed earned the title of "civil engineer." He had learned to survey, run levels, and draw maps and profiles. He had learned to manage construction and repair operations and to formulate cost estimates. Jervis had constantly studied the work done by superiors, so whenever a chance came for advancement, he was always ready for it.

Jervis carefully studied the plans provided by the office of the Chief Engineer for locks, wooden aqueducts, waste weirs, and culverts. As he gained experience and confidence, he began to initiate his own technical designs. This was a critical step in his professional development:

> Holding strict ideas of discipline, I was very careful . . . to fully understand and strictly carry out all directions from my superiors . . . They rarely made complaint of my operations but often gave me encouraging words, implying satisfaction with the direction I had exercised. As time went on, and I had become more familiar with the wants of such works, I gradually began to criticize the plans, being careful to keep my own counsel until I had fully matured my views in every particular. 10

On the Erie Canal, Jervis learned most of his engineering in the field. It was a practical education that improved his ability to solve real and immediate problems. But the young engineer did not slight the academic side of his profession. To supplement his field lessons, he started acquiring technical literature. Jervis was not content to learn a new skill simply by imitating Wright, Canvass Wright, David Bates or N.S. Roberts. He began to read. He studied surveying and drawing, mathematics, mechanics, mill-wrighting, carpentry, architecture, hydraulics, and natural philosophy.[11] In 1830, in a letter to Professor James Renwick at Columbia College, he faulted those early American engineers, even the "most eminent" ones, who had not done the same:

> In the profession generally, there is doubtless a great deficiency in scientific knowledge. This in great measure may be attributed to the limited education of a large portion of those who were early admitted to subordinate stations in the parties of engineers, and who by their application becoming familiar with the ordinary duties and the plans of construction pursued on the work in which they were engaged, were considered engineers, without ever having made much inquiry into the reasons or principles of what they had been doing or its applicability to other situations. 12

After serving for two years as a supervising engineer on an operating 50-mile stretch of the Erie, Jervis left the canal in March, 1825. In his own words, he was "engineer seeking new fields of occupation," and he "looked to new enterprises."[13] Jervis wanted to better himself, professionally and finacially, by working on a new project. In doing so he was following a common pattern for early civil engineers in this country. They sought out the most lucrative and challenging work, and after completing it, they quickly moved on. Often they did not even stay to completion. In the 1820s and 30s, the best engineers rarely remained long in any one place.

Benjamin Wright hired Jervis as an axeman in 1817; in 1825 he hired him as Principal Assistant Engineer on the Delaware and Hudson Canal. Although he was second in command, Jervis organized the engineering department and superintended the work, because Wright, busy working on several projects at once, was largely a Chief Engineer in absentia. Wright maintained final authority, but Jervis routed the canal and prepared its plans and specification. When Wright resigned his position in 1827, the canal company appointed Jervis its Chief Engineer.

In the spring of 1830 Jervis resigned from the Delaware and Hudson to become Chief Engineer of the Mohawk and Hudson Railway. In 1833 he returned to canal building as Chief Engineer of the Chenango Canal, which ran 98 miles from Utica to Binghamton, New York. While working on the Chenango he also consulted on the proposed enlargement of the Erie Canal, and when New York State began the enlargement in 1836, Jervis served as Chief Engineer on the Erie's eastern division. Jervis, however, did not work long on the new Erie project. On September 27, 1836, he accepted the position of Chief Engineer of the Croton Aqueduct. [14]

The Water Commissioners terminated Douglass on October 11, and Jervis took over nine days later. If Douglass had been too academic, lacking in experience and in the confidence necessary to erect the Croton Aqueduct, John Jervis suffered from none of these ills. He took command in a literal sense, and within a few days the project was his. In 1842, when describing the first flow of Croton water into Manhattan's distributing reservoir, one of Jervis' subordinates wrote that "our Chief Engineer arranged his corps and made his movements with all the circumspection and tact of a Napoleon." Fayette B. Tower's remark aptly underscored Jervis' dominant role in building the aqueduct, and he intended no perjorative. Tower also described the Chief Engineer as "a man of so much worth" who had shown him "so much kindness." [15]

When Jervis arrived in New York, the Water Commissioners were anxious to begin construction immediately, but Jervis checked their impatience and earned a needed delay. Because winter was coming, even if they contracted for work, virtually no construction could go ahead until spring. And because Douglass had produced few if any final plans for the aqueduct, the engineers would not be ready for construction until after the winter. Actually, even if Douglass had left complete plans and specifications, Jervis still would have pressed for a delay until spring. He would have insisted upon fully evaluating those plans before any contractors started work.

Because of their conflicts with Douglass, the Water Commissioners were also anxious to clarify the proper working relationship between themselves and their Chief Engineer. They sought "perfect harmony and confidence" between the two parties. After discussing the subject with Jervis, on November 19 the Board passed a resolution that delineated his responsibilities, while making it clear that he did not head an autonomous department.[16]

Jervis was to recommend applicants for engineering positions and supervise his department's work -- but the Commissioners maintained final authority in all matters relating to the engineers. Jervis was responsible for preparing all maps, drawings, and working plans, and for selecting materials and establishing standards of workmanship -- but his plans were subject to review. After the plans were approved, Jervis was to write contract forms and assist the Board in letting contracts. Once contracts were let, it was "under the immediate inspection and control of the Chief Engineer" to see that they were faithfully performed -- but the Commissioners, not the engineers, served as final judge in any contractual disputes.

The resolution made several other points. It set the Chief Engineer's salary at $5,000 per year and recommended that he "enforce a reasonable and just discipline" within his department. It informed Jervis that all engineering drawings "must be plain and without ornamental painting," and that in most instances the engineers would provide needed surveying instruments. Jervis agreed with this last point, believing that "It is no doubt most proper that Engineers should furnish their own instruments. This arrangement is most compatible with the proper dignity and character of the profession."[17] Jervis, in fact, agreed with all the points in the resolution, but he noted an important omission:

> In deciding on the plans that may be proposed by the Chief Engineer, while the Commissioners should have the right to make such modifications as to them appear necessary and proper, it should be considered in the right of the engineer to decline a superintendence if in his opinion, the mode determined on by the Commissioners is unsafe, or such as would in his opinion, be hazardous to his reputation as an engineer. 18

Jervis recognized the politics of the situation; the Board of Water Commissioners always had the final say. Yet as the engineer, he naturally wanted his plans approved with a minimum of debate or interference. So to strengthen his position, Jervis held out a trump card. If the Board interfered in a significant way, he would disclaim the Board's decisions and perhaps even resign -- a move that would greatly embarrass the Commissioners who had already gone through one Chief Engineer.

If the Commissioners were anxious upon Jervis' arrival, so were the subordinate engineers hired by Douglass. Their Chief had been fired, and their own positions were certainly suspect. They knew a potential conflict existed with the new Chief Engineer, who might choose to replace them with hand-picked men.

As the work progressed and required more engineers, Jervis did employ several men who had worked for him before. In the spring of 1837 he brought in Peter Hastie as a resident engineer and Edward Tracy as an assistant engineer. Both had worked under Jervis on the Chenango Canal. Late in 1837 Horatio Allen joined on as the principal assistant; previously he had served with Jervis on the Delaware and Hudson Canal. Jervis also hired his younger brother, William, as a resident engineer, and James Renwick, Jr., the son of a professional acquaintance, as an assistant.[19] But even as he brought in his own men, Jervis tried to avoid "wounding the feelings or disappointing the expectations" of those hired by Douglass.[20] He conducted no purge, and several of Douglass' men, particularly Edmund French and Henry T. Anthony, served well under Jervis for the duration of the project.

Jervis quickly relieved his subordinates of any feelings of job insecurity. At the same time, however, he let them know that the new man in charge had strong opinions about how a professional engineer should conduct himself. On November 10 he wrote H.T. Anthony that:

> The work on which we are engaged is a highly important one, and demands steady devotion of purpose in all its important agents; and I confidently expect your cordial cooperation in every measure designed to give energetic supervision and efficiency to its business concerns.

Jervis then noted that Anthony's engineering party started work too late in the mornings:

> The days are too short, and to make much progress in field work it is indispensable to have an improvement of their early hours. This remark is made, not that I have the least doubt of your

> industry and application -- but because I have observed the parties commence at a later hour in the morning than has been usual in the operations I have heretofore conducted.

On the same day Jervis wrote Anthony, he also wrote Edmund French. He asked French to inventory the drafting and surveying equipment in his Sing-Sing office (see Appendices I and II), and he instructed French to

> Have pitcher, bowls, glasses, candlesticks, etc. properly cleaned and set up and the instruments and table so arranged as to admit of being kept in order. Remove from the office articles that do not belong to it and which only promote confusion. Allow no one to derange the order of the office, or to remove papers of any kind without direction. Allow no smoking and no play of any kind in the office. In all respects let it be strictly a place of business. 21

Several months later, Jervis wrote a general circular to his resident engineers, including Anthony and French. By now there was no need to chide them for late starts or to imply that their offices were unkempt. He spoke of the Croton Aqueduct in terms of professional success and ambition:

> In the work you have undertaken, great vigilance, discrmination and firmness in the prosecution of its several duties, are indispensable to its successful accomplishment . . . It may be viewed, not only as involving great responsibility, but as highly exciting to professional ambition, and without the strong motive of ambition, no important member of the Department can be expected to be eminently useful in its accomplishment. 22

While infusing his assistants with an energy and dedication to match his own, Jervis collected the data needed to design the aqueduct. From October 20 into early November he walked the 33 miles of line located north of the Harlem River by Major Douglass. He approved of the plan for a 40-foot dam on the Croton. He thought its proposed location "at the Bluff rock" below Garretson's Mill was "probably a good one," although the dam might advantageously be moved "a short distance further down the river."[23] As Jervis examined the center line staked from the dam to Yonkers, he noted the positions of the numbered station markers placed every 50 feet. He thought that between stations 76 and 90 "the line may be improved," and that between 172 and 205 "it may be improved by laying 5 to 10 feet north."[24]

On the basis of his impressionistic examination, conducted without instruments, Jervis came to believe that the Douglass line, although imperfect, was in the main well-placed. Still, he might have significantly altered the line in a few locations, if the Water Commissioners, hoping to expedite matters, had not urged him to follow the Douglass line. They already had its land maps and were proceeding to obtain the needed right-of-way by appraisement.[25]

After walking the route, Jervis returned to his New York City office with a good appreciation of the technical problems posed by the environment. He saw that in Westchester some 16 tunnels from 160 to over 1200 feet in length were required; that 25 streams crossed the line at a depth of 12 to 70 feet below grade; and that over 100 culverts were needed to carry streams and run-off away from the conduit. Despite the complexity of the problems, Jervis evinced no doubts about his ability to solve them. With the assistance of his engineers, he continued to gather the diverse data he needed.

Edmund French prepared a map and profile of the line from the Croton to Tarrytown.[26] The profile showed Jervis the aqueduct's gradeline in relation to natural ground levels. Jervis could see where embankments or bridges were needed and how tall they had to be. He could see each rise inthe ground that required a tunnel or excavation. French also prepared transverse sections showing the steepness of the hills the line ran alongside of. Using these sections, the Chief Engineer could devise protection walls to guard the aqueduct against erosion and slides. Finally, French provided geological data. He sank shafts every 220 yards and recorded the types of soil and rock he encountered.

H.T. Anthony checked the aqueduct's line from Tarrytown to the Harlem River. He reset any stakes vandalized by Westchester residents unhappy with New York City's intrusion into their domain.[27] T.J. Carmichael, an architectural draftsman, traveled the line between the dam and Tarrytown in search of stone quarries.

Most stone near the line was gneiss, a metamorphic rock whose mineral constituents -- combinations of feldspar, hornblende, mica and quartz -- were arranged in layers. Because of its stratification and the structural instability of some of its minerals, most of this gneiss was unlikely "to be very durable when saturated with water and still less so when exposed to freezing and thawing."[28] Some of the gneiss, however, was less stratified and composed principally of feldspar. This gneiss, called "bastard granite," was more durable and fit for bridge construction and other heavy work. True granite was available from only a few isolated quarries. Fortunately, the largest granite quarry was located only two miles from the site of the dam. Carmichael wrote Jervis descriptions of the quarries and sent him a large number of specimens. He also reported on coves along the Hudson where contractors could get clean sand for mortar.

While his subordinates gathered information in the field, Jervis compiled his own data on local labor and materials costs.[29] How much would contractors have to pay for a bushel of quick lime or hydraulic lime? For a bushel of sand? For 1,000 hard bricks? How much would it cost to hammer dress a cubic yard of stone for an arch? What was the going rate for a bricklayer and tender? While he gathered this information and began piecing it together to form the Croton Aqueduct, two concerns dominated all the small details.

First, Jervis was very much aware of the fact that he was not building just another railroad or canal. These things could occasionally break down. Canals could breech and railways stop running, but such aggravations were usually not all that serious. The aqueduct, however, was another matter entirely. It was to become a life line to New York, and it had to be durable, permanent, and constant. Jervis was very much aware of the Roman aqueducts, many of which had functioned for centuries. He felt that the Croton Aqueduct, too, had to be built not just for now, but for ages to come.

His second dominant concern was the lack of immediate precedent:

> The enterprise of the Croton Aqueduct was an improvement for which there was no specific experience in this country or hardly any in modern times. It was hydraulic, and in this respect resembled canals; but it had no parallel in canals. In short, it presented at that time many features that had no specific guide from experience in this country. 30

The very newness of this large work, which would traverse especially difficult terrain in a harsh climate, demanded that Jervis be innovative in his design. But Jervis was never entirely comfortable as an innovator. He was very ambitious. He fully realized that new, daring structures would enhance his reputation. Yet he also realized that innovation was a risk. A success would signal progress to his career and his profession, but he had to weigh that success against the possibility of a time-consuming and expensive failure.

Jervis was not daring. He was not a trial-and-error engineer. When designing an innovative structure he sought support from theories based on "well-established and thoroughly analyzed facts." He tried to find engineering precedents that at least in part appeared applicable to the task at hand.[31] When the Chief Engineer, a conservative innovator, began in late December, 1836 to design the multi-million dollar Croton Aqueduct, he "did not hesitate to avail . . .[himself] of any hint of information that . . . [he] could obtain from any source that promised to be useful for the work." "Originality," he later wrote, was "regarded as subservient to success."[32]

Jervis drew upon his background of almost twenty years in engineering. He drew upon the unfinished work of his predecessor. He scoured the literature for help. He borrowed civil engineering practices from here and there, filtered them through his own philosophy of design, calculated their costs, and arrived at a plan which was his personal amalgam of theory, practice, and economy.

NOTES -- CHAPTER THREE

1
Neal FitzSimons, ed., The Reminiscences of John B. Jervis (Syracuse, 1971), pp. 119-120.

As FitzSimons notes in his "Preface," p. ix: "This book is based on a series of autobiographical sketches, entitled 'Facts and Circumstances in the Life of John B. Jervis, by himself,' probably begun after the author's fiftieth year and continued past his eightieth year." Jervis' work in manuscript form is maintained by the Jervis (Public) Library; Rome, NY.

2
Allen, Courier and Enqirer, November 12, 1840.

3
Van Schaick later claimed to have had Allen's sanction, but Allen denied it. See published letters from both men in New York Evening Post, April 29, May 3, 13, 19, 22, 24, 27, 1845.

4
Allen, Courier and Enquirer, November 12, 1840.

5
All three letters are in the Jervis Papers.

6
This biographical sketch of Jervis' early life and engineering career was condensed from Reminiscences of JBJ, pp. 29-119. For another account of his career, taken largely from the same source, see Elting Morison, From Know-How to Nowhere (New York, 1974), pp. 40-71.

7
Jervis to S.B. Roberts, March 9, 1838, Jervis Papers.

8
Reminiscences of JBJ, p. 21

9
Jervis, "Memoir of American Engineering," p. 53, MS dated March 1, 1876, Jervis Library. Published as "A Memoir of American Engineering," Transactions of the ASCE, 6 (1878).

10
Reminiscences of JBJ, p. 47.

11
Jervis' personal library still exists as a special collection within the Jervis Library.

12
Jervis to Renwick, April 6, 1830, Jervis Papers.

13
Reminiscences of JBJ, p. 64.

14
Jervis to Allen, September 27, 1836, Jervis Letter Book.

15
Tower to Helen M. Phelps, July 8, 1842; Tower to John Wolcott Phelps, September 2, 1842; John Wolcott Phelps Papers, Manuscript Division, New York Public Library.

16
"Resolutions of the Board of Water Commissioners," November 19, 1836, Jervis Papers. Also see Jervis to Water Commissioners, October 5, 1836, Jervis Letter Book; and Stephen Allen to Jervis, November 4, 1836, Jervis Papers.

17
Jervis to Resident Engineers, April 1, 1837, Jervis Papers.

18
Jervis, "Remarks in relation to preamble and Resolutions for the regulation of the Engineer Department," November, 1837, Jervis Papers. Although dated 1837, it seems very likely that these "Remarks" were actually written in 1836.

19
See Hastie to Jervis, November 20, December 6 and 22, 1836, Jervis Papers; Jervis to Hastie, December 13, 1836, Jervis Letter Book; William Jervis to John Jervis, January 17, 1837, Jervis Papers; and Reminiscences of JBJ, p. 126.

The engineers on the Croton project fell into a five-level hierarchy:

Title	Salary
Chief Engineer	$5,000/year
Principal Assistant	$3,500/year
Resident	$1,500/year
1st Assistant	$75-100/month
2nd Assistant	$50/month

The 1st and 2nd Assistants were not fully-trained, competent engineers. They were working "students" learning the profession, and their low salaries reflected that fact.

20
Jervis, "Memo for Comissioners Meeting," November 12, 1836, Jervis Papers.

21
Both letters are in the Jervis Papers.

22
Circular dated May 30, 1837, Jervis Papers.

23
See the entries for October, 1836, in Jervis Memoranda Book, Jervis Library.

24
Jervis Memoranda Book, p. 8; Reminiscences of JBJ, p. 121.

25
See Allen, "New York Water Works No. 3," and Blake, pp. 148-150.

26
Jervis to French, November 10, 1836, and French to Jervis, December 28, 1836, Jervis Papers.

27
Jervis to Anthony, November 10, 1836.

28
Carmichael to Jervis, December 21, 1836, Jervis Papers.

29
Jervis, "Report to the Board of Water Commissioners," December 23, 1836, and "Estimate for brick and stone masonry," n.d., Jervis Papers.

30
Reminscences of JBJ, pp. 121, 153.

31
"Memoir of American Engineering," MS, p. 58.

32
Reminiscences of JBJ, p. 122.

CHAPTER FOUR

In the winter of 1836-37, Jervis did not have time to design the Croton Aqueduct all at once. He had to let contracts the following spring, but he could not ready the entire line by then. So, although he saw the aqueduct as a system whose parts had to function harmoniously, he designed it piece-meal. He started with the structures along the 8-1/2-mile stretch of line from the dam to just below Sing-Sing. He decided to put that part under contract before worrying about the rest.

Jervis worked first on the general cross-section of the masonry conduit. He briefly considered a "double aqueduct" whose side-by-side channels would share a common inside wall.[1] Twin conduits would lessen the chance of any long interruption in the delivery of water. If one channel failed, or had to be shut down for inspection or repair, the other side could maintain service. But Jervis dismissed a double aqueduct on economic grounds. Its promise of greater constancy did not compensate for the fact that it would cost much more than a single conduit, such as the last one conceived by Major Douglass.

Douglass had been on the right track with his "horse-shoe" conduit, but Jervis saw room for improvement. In particular, he felt that Douglass had squandered material on the conduit's top and skimped on the bottom.

The aqueduct was to be free-flowing and gravity-fed. Water would not flow under pressure, and an air space would always exist between the water and the roofing arch. Consequently, this arch required no great thickness to resist internal pressures; it was simply a roof to be covered with three or four feet of earth to protect the conduit from frost.[2] Yet Douglass had intended to carry courses of stone up and over the brick top arch. Figured at 20 cents per cubic foot, Jervis estimated that this reinforcement would cost $12,000 per mile. Since Jervis believed the reinforcement superfluous, he omitted it.

While deleting the reinforcement on top, Jervis added material where Douglass had skimped. Douglass' last design showed no foundation running clear across the bottom of the conduit, where it would have to support a load of water weighing 62-1/2 pounds per cubic foot. Jervis felt that the aqueduct was most likely to fail at the juncture of the bottom and the side walls, so he added a foundation. He put 3 inches of concrete under the sides, and 6 inches under the inverted arch.[3]

If the aqueduct had not been so long, Jervis might have stopped with the above two changes. He continued to modify the conduit because "in view of the great amount [of masonry] required, a small difference in the facility of construction should not be disregarded."[4]

In his first design report submitted to the Water Commissioners on December 23, 1836, Jervis retained the conduit's horse-shoe shape; the bottom formed by an inverted arch of brick;[5] the sloped, flat sides; and the brick top arch. But he altered some important dimensions. Notably, he increased the chord line of the inverted arch from 6 feet to six feet nine inches, and he reduced the vertical rise of the sides while changing their inside batter or slope from 1 in 6 to 1 in 12. These changes opened up the conduit's interior, further reduced the amount of masonry in the structure, and made the conduit, because its side were closer to vertical, slightly easier to build. In economic terms, Jervis estimated that his preferred plan would run $93,900 per mile.[6]

Jervis was concerned with more than just the geometry and cost of the conduit; he had to assure himself that it would deliver the desired amount of water to New York. To gain this assurance, he turned to hydraulic formulae developed by Bossut, Dubuat, Prony, Eytelwein, Langsdorf and Robison. Jervis had John Robison's 4-volume A System of Mechanical Philosophy, and he often consulted this wide-ranging work because he considered Robison "a writer on Mechanical Philosophy of high authority and great practical usefulness."[7]

To study the other authors' works on hydraulics, such as Eytelwein's Handbuch des Mechanik fester Korper und Hydraulic (1801), the Chief Engineer resorted to summaries or translations published in English, because he had never been schooled in German or French.[8] One such summary, Charles S. Storrow's Treatise on Water-Works for Conveying and Distributing Supplies of Water, was published in Boston in 1835, just in time for consultation on the Croton project. Storrow's book contained several water-discharge formulae, some of which were also available to Jervis in Olinthus Gregory's Mathematics for Practical Men (London, 1825), in Thomas Tredgold's Tracts on Hydraulics (London, 1826), and in the 1832 edition of the Edinburgh Encyclopaedia.[9] Using formulae developed by Robison, Prony, Eytelwein and Langsdorf, Jervis calculated that water in his preferred conduit, when running at capacity, would flow with a velocity of 1.725 feet per second, meaning that New York could expect a maximum delivery of 60 million U. S. gallons per day.[10]

When the Water Commissioners reviewed Jervis' first design report, they were pleased with his ability to reduce the masonry in the conduit without sacrificing its structural integrity. Yet they were not so pleased with one material he chose to use. Because the "constant and successful operation" of the conduit depended on a durable and impervious bond between its part, Jervis had recommended that all cement, grout and concrete be made with hydraulic lime. This material cost almost twice as much as common quick lime, but Jervis believed the aqueduct called for its greater convenience and especially its durability. Unlike mortar made with quick lime, hydraulic mortar set quickly in a variety of environments: dry, damp, or even under-water. And once it set, hydraulic mortar was much less likely to be leached or washed out by water.

American civil engineers had been using hydraulic lime for some 15 years, ever since Canvass White discovered it while serving as principal assistant engineer on the Erie Canal.[11] Yet because of its cost, engineers had used it sparingly. They generally used hydraulic lime only in the face of a structure, where it was constantly exposed to water. Behind the face they resorted to quick lime, or to quick lime mixed with a small percentage of hydraulic lime. Jervis had followed this practice when building canals, but for the aqueduct he thought any resort to quick lime was false economy.

The Chief Engineer was unwilling to gamble on a cheaper material that might cause a disastrous breech, if it failed to harden properly. Jervis leaned towards "the opinion of some engineers, that in very heavy walls in damp places, pure quick lime will never obtain a good set." To substantiate this, he cited the case of a 30-year-old canal lock which had been constructed with quick lime. When workers had taken the lock down, "the mortar in the backing was found to have made no set of consequence." So although it meant an additional expense of approximately one-quarter of a million dollars, Jervis strongly recommended the exclusive use of hydraulic lime:

> The most of my time for near[ly] twenty years, has been employed on hydraulic works, where it has been considered important to lay all masonry exposed to contact with water, as requiring particular permanence, in hydraulic cement. In reviewing those works, not one of them appears to me, to have required in so eminent a degree, the use of an entire hydraulic cement, as the work under consideration.[12]

Because of this recommendation, Jervis' first design report once again raised the issue of the balance of power between the Water Commissioners and the Chief Engineer. Douglass had intended to use quick lime in the backing of the conduit, and the Commissioners also believed that quick lime would suffice. Jervis argued to no avail that hydraulic lime was necessary to secure impervious, durable masonry. Since its technical merits did not sway the Commissioners, Jervis changed his tack. He played the trump card he reserved for use only when the Board significantly interfered with his work. If they decided to use quick lime, he would place his expertise and reputation in opposition to their decision. The new tack worked:

> After exhausting what I had to say, and seeing no prospect of the board agreeing to my views, I said to them that I could not consent to the use of quick lime in any part of the masonry. It was no doubt a cheaper material but did not appear to me as affording the best security for the work, and if the board insisted on its use, they must assume the responsibility of the measure. This closed the discussion, and the board immediately adopted the specifications in full.[13]

In a sense, both Jervis and the Water Commissioners benefited from this early confrontation. Instead of creating friction, it delineated their respective and valid interests. The Water Commissioners truly held their positions as a public trust. They wanted the best aqueduct they could get for the least amount of money. Unfortunately, by December 1836, the Commissioners must have known that their 1835 estimate of 4-1/2 million dollars for the work was absurdly low.[14] Jervis estimated materials costs at much higher rates than Douglass ever had, and land costs had dramatically increased.[15] As the commissioners saw the cost of the aqueduct escalate, they determined to check it wherever possible.[16] Their frugal stance on quick lime, then, served to impress upon Jervis the need for cost-cutting measures. At the same time, Jervis impressed the Commissioners with his professional pride and integrity. He earned from them a deference that they had never paid his predecessor.

On December 27, 1836, just four days after submitting his conduit plan, Jervis reported his plan for carrying the conduit along hillsides and across low areas.[17] Where the aqueduct ran alongside slopes, he proposed the construction shown in the illustration. This plan protected the conduit from erosion and slides in three ways. First, the Chief Engineer seated the structure securely in the hillside, effecting "a lodgement that may not be disturbed." Where the aqueduct's grade line ran sufficiently below ground level, Jervis simply buried the conduit in the hill. Where the grade line caused the conduit to protrude from a hill, he had to take more stringent precautions. He placed the conduit on a heavy stone foundation wall that reached far enough into the ground to achieve a firm footing.

To further protect the conduit's stance, Jervis put a supportive embankment on its downhill side. A stone protection wall, "well settled in the hill at its foot," rested on earthen fill and leaned into the conduit. Jervis chose this mixed construction, instead of an embankment made entirely of earth, because the stone facing offered more protection from erosion. Also, the stone wall could stand at a steep angle, so it permitted a narrower embankment. An earthen embankment, graded at a gentler slope, would have extended much further down the hill.

Jervis also guarded against heavy rains and the run-off that might course down a hill and undercut the masonry. Where the conduit was buried, he simply carried the water over it in a paved channel. Where the conduit protruded from a hill, Jervis called for strategically placed "drop-well" culverts that collected water and channelled it under the aqueduct. This type of culvert, made of well-hammered masonry laid in hydraulic cement, is shown in an illustration.

After dealing with hillsides, Jervis dealt with the problem of "passing ravines, or grounds that fall below the grade line of the Aqueduct."[18] He anticipated that four aqueduct bridges would be needed along the entire route to pass particularly wide or deep valleys. These bridges would be needed over the "kill" or brook in Sing-Sing, over Mill River in Sleepy Hollow near Tarrytown, over the Harlem River, and, once on the island, over Manhattan Valley. Of the four, only Sing-Sing merited prompt attention, because it alone fell within the first 8-1/2 miles of the line. Still, because an aqueduct bridge posed special problems, Jervis deferred discussion of his plan for Sing-Sing until he could prepare a special report on that site. For the time being he concerned himself with an embankment plan to be used at numerous valleys.

In his 1835 consultant's report, Major Douglass proposed carrying the conduit across shallow valleys on what appeared to be a mound of rubble stone dumped in as fill:

> In embankments. . .it is proposed to construct the work. . .by forming as a foundation, immediately under the base of the conduit. . ., a mound of solid stone. . ., this material being found in sufficient abundance everywhere on the line, and forming in this way, as the writer has occasion to experience in similar situations, a cheap and very safe foundation. The residue of the embankment after the conduit is built, is then to be formed to the necessary height and width, with good gravel, or loam, on the slopes of which, in situations requiring enclosure, live hedges, of a proper kind, may be profitably and tastefully cultivated.[19]

John Jervis, like Douglass, had an admirable respect for nature. He delighted in the rigors of field work and reveled in "wild surroundings" that would someday yield a new canal or aqueduct. But when it came to designing embankments, Jervis thought more highly of stone protection walls than he did of tastefully cultivated hedges "of a proper kind." As in the case of the conduit's design, Jervis believed his predecessor's embankment plan needed considerable improvement.[20]

Besides rejecting live hedges, Jervis rejected the idea of supporting the conduit on a mound of stone simply dumped into place. The mound could slide or settle unevenly, creating cracks in the masonry. In lieu of Douglass' approach, Jervis chose an embankment plan very similar to his plan for supporting the aqueduct on hillsides. Jervis placed the conduit on a trapezoidal wall composed:

> of large stones laid in a rough but compact manner, the interstices between the stone[s] and to level up the courses, to be filled with fine broken stone, so as to give firmness and stability to the work.[21]

This foundation wall, laid without mortar, was more expensive than the mound of stone proposed by Douglass, but it appeared to offer much more security for the conduit. At the same time, it was less expensive than another plan that Jervis had considered. Over the aqueduct's entire run, he believed a dry foundation wall laid would cost a half-million dollars less than a wall "of solid hydraulic masonry."[22] Since the wall contained no mortar, it did require a heavy earthen embankment on both sides to assure that it "kept in place." If the height of the embankment demanded it, the earth, in turn, was to be kept in place by a stone protection wall.

The aqueduct along hillsides needed protection from heavy rains. So did the aqueduct that crossed a valley on an embankment. Even in normally dry valleys, Jervis called for culverts to carry run-off under and away from the line. The Chief Engineer standardized those culverts that were from 2 to 12 feet wide. They had inverted arches on the bottom, vertical side walls, and arches tops.[23] Once his engineers had completed plans for the standard culverts, Jervis could choose one of a proper size for a given valley and conveniently plug the structure into the line.

No standard culvert sufficed at Sing-Sing. The kill, or brook, that ran through the village was small, but it had carved a substantial valley. When Major Douglass first proposed the Hudson River route, he recognized Sing-Sing Kill as a major obstacle on the way to Manhattan. Consequently, when he ran the line through Sing-Sing he took particular care to seek out the best passage. Still, he left Jervis with the problem of crossing a depression 536 feet wide that fell to slightly over 70 feet below grade.

Jervis faced more than natural obstacles at Sing-Sing; he faced man-made ones as well. As it crossed the valley the aqueduct's line intersected two village roads that the Chief Engineer had to accomodate, because he had no authority to move them. The line ran almost perpendicularly to the first road and passed it shortly after entering the valley. This road posed no significant problems; Jervis spanned it with a relatively small viaduct arch.

The second road, however, was situated in a "peculiar manner," as Jervis called it.[24] The road crossed Sing-Sing Kill on a wooden bridge as it ran to a small water-powered mill. The aqueduct's line intersected the road at a sharp angle right over the deepest part of the valley--and right over the road's wooden bridge. Jervis' structure, then, had to span an already existing bridge. It also had to contend with a house located between the two roads. The line passed right behind the residence and cut it off from the owner's garden. On May 25, 1836, the State Legislature had passed an act that anticipated this sort of unfortunate situation and protected the rights of property owners. It required New York City to:

> erect and sustain convenient passes across or under the aqueduct whenever said aqueduct shall intersect the land in said county of Westchester, belonging to an individual, or individuals, for the farming and other purposes of the land thus intersected.[25]

Because of this legislation, the Chief Engineer had to make sure that the home-owner retained free and easy passage between his house and garden.

After considering the diverse problems posed by this valley, on February 8, 1837 Jervis presented the Water Commissioners with a "Report of Sing-Sing Kill Aqueduct Bridge." Although he referred to the entire 536-foot-long structure as a bridge, for most of its length a solid stone wall, laid in cement, supported the conduit. Where the wall intersected the first road, Jervis put in a low arch spanning 20 feet, built slightly askew since the road and the wall did not quite meet at right angles. After passing the first road, the wall resumed for some 120 feet, its facade broken only by a small arch for the home-owner, before it encountered the second road and its wooden bridge. To pass this obstacle, Jervis specified an impressive aqueduct bridge having a single elliptical arch spanning 80 feet. The underside of the arch stood nearly 70 feet above the stream's bed. At the termination of the bridge, Jervis again commenced the solid wall and carried it approximately 190 feet to complete the crossing.

Jervis exhibited considerable ambivalence towards this design. If the aqueduct's line had not passed so near the house, he probably would have thrown a wide embankment across most of the valley, instead of the narrow, solid wall. And in particular, if the line had not crossed the second road in such a "peculiar manner," he would have shunned the aqueduct bridge, with its large arch, in favor of one or two culverts placed under the embankment to straddle Sing-Sing Kill.

The challenge of building the bridge excited the Chief Engineer, who fully realized that well-executed bridges were status symbols among civil engineers. They were baubles to delight one's peers. Yet he would have avoided this bridge, if he could have, for two reasons: cost and stability. Its large masonry arch was expensive because it required extremely good stone that had to be cut and fitted precisely. But an even greater liability, and the one paramount in Jervis' mind, was the susceptibility of the large arch to deterioration, if any water from the conduit leaked into the masonry and froze. He feared that in New York's climate, "leakage amounting to only a sweating of the arch stone in the bridge masonry would tend to disintegrate even the most durable stone.[26]

Jervis told the Water Commissioners that many aqueduct bridges had exhibited this tendency, even the ancient Roman structures that had been built in a much milder climate:

> It may be observed that even in Rome, that portions of their aqueducts, which are elevated on bridges of masonry, have often required extensive repairs. . ., and those portions of the Roman aqueducts, which have stood, undisturbed, the test of time, are placed underground, and therefore, not exposed to material atmospheric changes.

English aqueduct bridges, too, had suffered:

> In the stone aqueducts for the English canals they formerly adopted the plan of lining the inside with well puddled earth. This earth was found to heave by frost, and this produced the same derangement in the masonry as had been experienced when the masonry only was depended upon. It was not infrequently the case that a portion of the masonry in a few years required to be supported by strong bars of iron, or taken down and rebuilt.

As for American aqueduct bridges, Jervis found them "quite too leaky, to promise the durability required in the Croton Aqueduct." The Little Falls Aqueduct on the Erie Canal had been in service only 12 years before exhibiting "decided marks of injury from frost."[27]

Forewarned of the danger, the Chief Engineer sought means of protecting the masonry in the Sing-Sing Kill Aqueduct Bridge. The first step, naturally, was to try to make the conduit water-tight. Jervis searched the literature and discovered that Thomas Telford, "an eminent English engineer," had placed a cast iron floor in an aqueduct bridge on the Ellesmere Canal. Thirty years later, "the aqueduct was tight, and in all respects appeared in good condition." Following Telford's lead, engineers on the Glasgow and Union Canal had lined three aqueduct bridges with cast iron on the bottom and sides. These structures, too, escaped injury from frost. Citing these precedents, Jervis wrote the Commissioners:

> After much reflection I have come to the conclusion that the aqueduct over heavy arches, after being made of the best hydraulic masonry, should be lined with cast iron, made impervious to water.[28]

The Chief Engineer's lining, made of plates five-eighths of an inch thick, went between layers of brick on the sides and bottom of the conduit.[29] These plates offered the best known protection against leakage, but in case they failed, Jervis provided a means for any water to drain out of the structure before doing any harm. If the conduit leaked, the water that ran down the arch barrel would be carried outside the structure by small copper pipes.

The Chief Engineer took one other important step to preserve the large arch above Sing-Sing Kill. He reduced its superincumbant mass, believing that the less load on the arch, the longer it would last. The bridge's deck--the masonry conduit, lined with cast iron, filled with water, and topped with earth--would place a heavy load on the arch that Jervis could not reduce. He could, however, reduce the dead-load imposed by that part of the bridge that supported the deck and carried its load down to the arch. In most masonry bridges of the period, builders used an earthen or rubble fill to support the deck.[30] Jervis chose not to follow this practice. Instead of totally filling the space bounded by the arch barrel, the exterior spandrel walls and the deck, he supported the deck on a series of interior spandrel walls, tied together with cross-walls. By leaving large spaces between the walls, and by leaving hollow spaces in the walls themselves, he significantly reduced the dead-load on the arch.[31]

At Sing-Sing, man-made obstacles posed serious problems. Fortunately, when Jervis turned to Croton Dam such obstacles were dispensed with. The Water Commissioners purchased all properties, including small mills, that would be flooded by the reservoir, and they received permission from the State Legislature to move a road and a bridge that were in the way. So Jervis did not have to warp the dam's design to protect any existing structures, but he did have to contend with formidable natural obstacles.

Major Douglass had marked a spot for the dam with a wooden stake. Although he was not bound to build precisely on this spot, Jervis was restricted to the short stretch below Garretson's Mill where the Croton contracted to a width of only 120 feet. Here water ran at a depth of 4 to 10 feet, and a stone bluff bordered the southern bank of the river. From the base of this bluff, a gneiss shelf ran under the river a short distance before giving way to a gravelly bed. On the Croton's northern bank, a sand table, rising three feet above the river, ran 80 feet before intersecting a sandy hill that rose at a 45-degree angle.

The Chief Engineer did not object to building a tall dam in this environment, because it would create a doubly useful reservoir. Besides storing 600 million gallons to draw from in dry seasons, the stilled reservoir would help purify the water before it entered the aqueduct, by allowing impurities to settle out. These benefits, Jervis thought, were "a sufficient inducement to encounter the difficulty and expense of a high dam." Still, as he considered the problems of building a connecting structure between the stone bluff and the sandy hill, he worried. It was one thing to build a dam across the Croton; it was another matter entirely to build a dam that would last. As usual, the Chief

Engineer's main concern was durability :

> In the case under consideration, it is inadmissable to contemplate even extensive repairs, and much less a renewal that would consume some months, and consequently suspend the supply of water from the aqueduct during that time.[32]

Because of the dam's height and the demand for permanence, Jervis dismissed the idea of timber construction; the over-flow weir had to be masonry. Masonry dams, however, were by no means immune to failure. A tall masonry dam required an exceptionally good foundation, preferably bed-rock, that would withstand the impact of falling water. Here was the engineer's greatest problem: neither he nor Douglass had found a line of solid rock going clear across the valley.

In November and early December Edmund French had tried once again to find such a line by boring into the river's bed. French met with no success before severe weather halted his efforts, and he could not resume work until the next summer brought both warm weather and low water. But Jervis, under pressure to put the head of the line under contract, could not wait for another examination. He had to design Croton Dam working with information already on hand, and that information told him only that the extreme southern side of the Croton Valley lent itself to a masonry structure.

Jervis decided to run the masonry dam's southern abutment right into the stone bluff, and if necessary he would cut the bluff down to provide room for the weir. Since he would not risk carrying the masonry beyond the gneiss shelf and onto gravel, he had to close the remainder of the valley with a massive earthen dam (or embankment), 15 feet taller than the overflow weir. The sloped embankment, constructed over wooden piers and backed by a heavy stone wall, would be secure as long as water never passed over it. Jervis studied previous floods along the Croton, and he convinced himself that this would never happen. The masonry weir would discharge any flood waters fast enough to prevent them from rising over the top of the earthen embankment.[33]

Jervis worked up two plans for the masonry weir. Apparently, he did not choose between them until the last moment, just before reporting to the Water Commissioners in mid-February 1837.[34] His first design for the profile of the dam's main wall is shown in the illustration. The Chief Engineer intended to lay this wall so that when viewed from the top, it would appear as a segment of a circle. The wall curved eight feet into the reservoir while running between two abutments 100 feet apart.

Jervis planned to lay a wall of impervious, puddled earth (a compacted mixture of clay, loam and gravel) against the dam's upstream face to protect the masonry from the deleterious effects of constant contact with water. The offsets, or steps, on this side of the dam conveniently reduced the thickness of the main wall as it rose. They also served "to check the water that will seek a passage between the masonry and the [puddled] earth." To further protect the upstream face, Jervis planned for a fore-embankment, a "triangular body of gravelly earth," to be graded at a slope of four horizontal to one vertical.

While Jervis was concerned with the stability of the dam's upstream side, he was even more concerned with its downstream face. The Chief Engineer believed that water passing over the weir represented "by far the most serious source of danger to the permanent stability of the work." For one thing, it would wear down the granite face stone and wash out its mortar. Secondly, the falling water might undercut the structure by tearing away at the dam's gneiss foundation.

Jervis documented the danger of undercutting by citing the history of the Fort Edwards Dam across the Hudson. Water passing that dam fell perpendicularly onto the river's slate bed. In only 12 years it had "taken rock of several tons weight and moved it, creating a chasm [10 to 20 feet deep] below the dam." To protect his dam, Jervis beveled the downstream face, which prevented water from falling perpendicularly over the weir. He also planned for an apron:

> that will receive the force of the falling water, and materially destroy its power, and throw its remaining action so far beyond the base of the dam, as to produce no injury.[35]

With the apron in place, water could not abrade the back of the dam, because it would not come into contact with it. Instead of running over the masonry, it would run over replaceable wooden plank affixed to the granite. And the water could not tear away at the dam's foundation, because instead of impacting directly on the bed-rock at the toe of the dam, it would strike on top of heavy, interlocking timber cribs filled with rubble stone and covered with thick planks.

In deciding on how much masonry his first design for Croton Dam needed to stand against the river and its floods, Jervis relied on an engineering rule of thumb:

> If we were to erect a wall of the most substantial masonry, to stand alone against a column of equal height of water, it would require a thickness equal [to] half of its height to resist the pressure. The same to sustain a bank of ordinary earth, would require by the most approved rules, two-fifths (2/5) of its height.[36]

To raise the Croton 40 feet, the dam's main wall had to rise fifty feet from its lowest foundation to the top of the weir. According to the rule of thumb, the wall required an average thickness of half its height, or 25 feet, to stand safely against an equal column of water. To stand against dry earth, the wall would have required a lesser thickness of 2/5 of its height, or 20 feet. But Jervis' wall had to stand against a "compound" pressure because of the fore-embankment. It had to stand against both earth and water:

> The earth embankment. . .[on the dam's upstream side] will be calculated to prevent the water from acting against it; but this earth, by becoming saturated with water, will from that circumstance act with more power [than dry, ordinary earth] to over turn or move the wall.[37]

To stand against the fore-embankment saturated with water, the rule of thumb instructed Jervis to build a main wall greater than 20, and less than 25 feet wide. The Chief Engineer called for a wall 30 feet wide at the base and 10 feet wide across the top. This wall had an average thickness of just 20 feet, so it was somewhat deficient in masonry. But Jervis did not intend to lay the wall in a straight line, as the rule of thumb presupposed. He planned to lay it along a curve, so it would function like an arch under a compressive load. Jervis substituted the curve for a thicker wall, and he believed the curve rendered the dam "perfectly secure against every contingency of pressure."

Despite his initial belief in the soundness of his first design for Croton Dam, Jervis apparently grew dissatisfied with it. He wrote the specifications for Croton Dam in April 1837, and the specifications called for a main wall having an altered profile.[38] This second design shared some important features with the first. It maintained the height of 50 feet and the length of 100 feet, the fore-embankment, and the downstream apron. Yet in other respects it was very different.

The changes Jervis made signified the depth of his concern over what water passing over the structure could do to its foundation. He obviously came to believe that water cascading over the first weir was not going to be thrown back far enough from the bulk of the masonry, or sufficiently slowed in its descent. Consequently, he changed the slope the downstream face, making it farther from vertical. Besides throwing the water further downstream, this change greatly increased the amount of masonry in the dam. To partially offset this increase Jervis omitted the steps on the upstream face and planned to lay that side of the wall plumb. Yet even with the omission of the steps, the weight of masonry in the wall was now so great that Jervis could lay it in a straight line. The curve's arch action was no longer needed.

The dam's main wall ran between two masonry abutments. The northern abutment securely connected with the earthen embankment that closed off the remainder of the valley. Jervis located a waste gate in this abutment, 20 feet below the top of the dam. In the event that men needed to work on the top or back of the dam, this gate could be opened to lower the reservoir's water level, so that men could proceed without fear of water passing over the weir. The Chief Engineer designed the southern abutment to serve as one of the two walls which enclosed the entrance to the aqueduct, or its gateway.

If placed precisely on the aqueduct's grade line, the floor of the 20-foot-wide gateway would have been 8 feet 5 inches below the top of the dam. But Jervis sunk the floor to 10 feet below the weir, so during a drought the aqueduct could draw water for a longer period of time.[39] Even when the reservoir was full, the sunken entrance had its purpose: to keep leaves, branches and other floating debris from entering the aqueduct. As another guard against debris (and fish), Jervis located a timber screen at the head of the gateway.

After flowing into the gateway, water had to pass through two sets of vertical gates before entering the conduit. The wooden guard gates were normally open. They would be closed only when it was necessary to shut off the water completely, so men could inspect or repair the second set of gates. The 10 cast iron regulating gates, 18 inches wide and 3 feet tall, were normally open. By adjusting them up and down, a gate-keeper could control or regulate the amount of water allowed into the conduit.

The chief Engineer sheltered the guard and regulating gates in a small "stone house" next to the dam. Even in the design of the gatehouse, Jervis exhibited his concern for the safety of the aqueduct. In this instance, he protected it from intruders:

> The windows to be secured by a grating of iron rods, let in and leaded to the caps and sills. The doors to be... made of narrow pine plank tongued and grooved, and lined with boards, and well hung with suitable fixtures and locks, to render it secure against improper approach. [40]

While Jervis was busy designing and redesigning Croton Dam, he finished the other plans needed for the first part of the aqueduct. In numerous places its grade line passed beneath ground level, so on February 16 Jervis reported a plan for excavations and tunnels. [41] This report dealt with the size and shape of open cuts in earth and rock, and tunnel cuts through rock. [42]

Where it was necessary to excavate earth to get down to grade line, Jervis required contractors to prepare trenches, 13 feet wide on the bottom, with sides carrying a slope of 3 vertical to 2 horizontal. In arriving at this plan for trenching, Jervis took 3 considerations into account. First, he did not want contractors to dig trenches any larger than necessary, because they were going to get paid for the cubic yardage of earth they removed. Secondly, although the trenches were not to be too large, they also could not be too small. They had to provide adequate working space for the men laying the conduit. Thirdly, the Chief Engineer had to protect the men and the conduit from sliding or collapsing earth.

Jervis thought that most earth would stand safely at his prescribed slope, but he recognized that "tender or wet" earth might require trenches whose sides were inclined further from vertical. In some instances, contractors might even have to shore up trenches with timbers. But the engineers, not the contractors, would specify any changes from the slope of 3 to 2. If a contractor dug a broader trench on his own, he would not receive any payment for his extra labor. Jervis placed similar size and shape restrictions on the other types of cuts.

On February 25, the Chief Engineer presented his last design report prior to letting contracts. For some time he had worried about ventilating the aqueduct. Whenever water was let into the conduit, or whenever the water's flow might be blocked suddenly by an obstruction, he wanted to prevent air in the conduit from becoming trapped and pressurized. Whenever the conduit was emptied, he wanted air to fill the space previously occupied by water, so that no vacuum formed. He also wanted to maintain the freshness of the water under transport.[43] It seemed that ventilators would serve all these ends, but Jervis had no idea as to how many were needed.

He turned to the literature for an answer, and in this instance the literature failed him. Robert Stuart's Dictionary of Architecture gave 120 feet as the proper distance between ventilators; Peter Nicholson's Architectural and Engineering Dictionary said 240 feet; and John Leslie, in Elements of Natural Philosophy, wrote that ventilators should be 600 feet apart.[44] Besides reading these technical works, Jervis studied an unlikely source on ventilators: a book called Sketches of Turkey, written by "An American." Jervis read fairly extensively in history, and he also read travel books, noting their descriptions of old and new civil engineering works around the world. In this travel book he was quite taken by the anonymous author's description of ventilators, or "Hydraulic obelisks," used on an aqueduct running to Constantinople. The description, however, did not solve his problem. It provided yet another contradictory answer. The "Hydraulic obelisks" were placed 300 to 500 yards apart.

Unable to find "any definitive rule" regarding ventilators, Jervis devised his own solution. He began with the premise that the spacings recommended in the literature had been adopted on successful aqueducts. Because the aqueducts had been successful, the various authors assumed their ventilators spacings were correct, "without considering that [ventilators] might have been sufficient at a greater distance." Working from this premise, and wanting to avoid the expense of superflous ventilators, Jervis solved his problem in a most pragmatic way, with some assistance from Stephen Allen.

Jervis "guesstimated" that one ventilator per mile would suffice, but to be on the safe side, he adopted an idea suggested by Allen. He left regular ventilator openings in the top arch of the conduit at quarter-mile intervals. These openings, covered with a removable flagstone and earth, would "afford a convenient facility for erecting more ventilators, if experience should indicate their necessity or advantage."[45] The Chief Engineer's "guesstimation" was a good one; one ventilator per mile proved sufficient.

Jervis suggested that two out of every three ventilators take the form shown in the illustration. He made these hollow stone "cylinders" tall enough to make it difficult for anyone to throw or drop things into the aqueduct. To further thwart such mischief, he also placed an iron grating over each opening. Every third ventilator was to be a larger, dual-purpose structure after the plan shown. Jervis dubbed this an "entrance ventilator." Air could pass in and out of the conduit, and so could inspectors or workmen, through a "door of close double batten oak, well riveted. . ., and secured with proper iron hangings, clasp, staples, and lock." Jervis made clear to the Water Commissioners his reasons for building these entrance ventilators:

> The plan of construction and the great freedom of the waters of the Croton from all earthy matter, renders it probable that repairs or the removal of earthy deposit will rarely be necessary. Still, it is not to be expected a hydraulic work of such extent will be entirely freed from such liability, and it would be inexpedient to construct it on a plan, that did not admit convenient entrance at suitable intervals. A ventilator and an entrance may be advantageously constructed together, and I have therefore prepared a plan to effect the double purposes.[46]

While entrance ventilators served two purposes, the waste weirs that Jervis discussed in his February 25 report served three. These waste weirs, after the plan shown, initially resulted from the Chief Engineer's concern over the need for an efficient means of draining and refilling the aqueduct. He recognized that if the gates at the dam were left as the only means of regulating water flow, then whenever the water was stopped New York would lose its running supply for too long a time.

To demonstrate the utility of the waste weirs (Jervis placed six of them along the line), assume that the aqueduct is completed, and the conduit across Sing-Sing Kill Bridge needs repair. Instead of sending a messenger all the way to the dam to stop the water, men enter a waste weir just a quarter-mile above the bridge. Inside this structure, the conduit has no roofing arch, and two waste gates are set into an altered side wall. The men drop wooden stop planks across the conduit and open the gates, diverting the water into a culvert that drains or wastes it into a nearby stream. Since the waste weir is so near the part of the aqueduct needing repair, workers can begin their task almost at once; they do not have to wait for a long column of water to pass them by. When the repairs are completed, men remove the stop planks and close the waste gates. The water again flows towards New York, starting from a point much closer to the city than the gates at the dam.

The waste weirs functioned primarily to stop and divert the water in the conduit, but because they had openings to the outside, they also functioned as ventilators. Wherever there was a waste weir, no regular ventilator was needed for a mile on either side of it. Finally, the waste weirs provided a means of automatically spilling surplus water. Jervis recognized that the gate-keepers at Croton Dam might "sometime neglect their duty" and allow too much water to enter the conduit.[47] Consequently, he thought it best "to make every reasonable provision to mitigate the injurious influences of such neglect." Within the waste weirs, Jervis set the normally closed waste gates in masonry that served as a side wall for the conduit--a wall that rose only 5 feet 9 inches above the conduit's lowest point. The water in the aqueduct, if it exceeded a depth of 5 feet 9 inches, passed over this wall, fell into a well, and then ran off in a culvert. Jervis believed that for many years New York would not require any more water than the aqueduct could deliver at this maximum depth. When it did require more water, the height of the side wall could be raised by adding wooden flash boards.

On February 28, three days after submitting his report on ventilators and waste weirs, John Jervis formally reported to the Water Commissioners that:

> Plans for all the work required from the head of the Croton Aqueduct to the State Farm at Sing-Sing have now been sumbitted.[48]

The initial design work was complete, but Jervis and his engineers still had a great deal of work ahead of them before construction could begin. And, as always, they had to hurry. On the same day he reported that all needed plans had been submitted, the Chief Engineer and the Water Commissioners placed notices in four New York City newspapers, and in Albany, Utica, Hartford and Philadelphia papers. The notices advised that the process of letting contracts on the Croton Aqueduct would begin on April 10, 1837.[49]

NOTES--CHAPTER FOUR

[1]Jervis, "Plan of Double Aqueduct," December 1836, Jervis Papers.

[2]This was the minimum depth of the earth covering the conduit, used wherever the aqueduct lay at or above ground level. Where the conduit was buried, workers would backfill over the masonry until the natural ground level was restored.

[3]Jervis, "Report to the Board of Water Commissioners," December 23, 1836, Jervis Papers.

[4]Ibid.

[5]Both Douglass and Jervis preferred brick for the shallow inverted arch because, unlike stone, it did not have to be dressed or shaped.

[6]Jervis, "Report to W. C.," December 23, 1836.

[7]Jervis to Stephenson, December 27, 1843, Jervis Papers.

[8]Even if Jervis had been able to read French and German, he would have had a difficult time trying to find some of these authors' early works in the United States, because of their early publication dates.

[9]All these volumes are found in Jervis' personal library.

[10]Jervis, "Report to W. C.," December 23, 1836; Jervis to Stephenson, December 27, 1843; Jervis Memoranda Book entry for December 12, 1837; and Jervis, "Calculations on disharge of pipes," n.d., Jervis Papers.

[11]Reminiscences of JBJ, p. 37.

[12]Jervis, "Report to W.C.," December 23, 1836.

[13]Reminiscences of JBJ, p. 123.

[14]In "New York Water Works No. 1," Stephen Allen suggests that Douglass and Martineau deliberately underestimated the aqueduct's cost, in order to promote their own employment on the project: "To show what dependence may be placed on the calculations of persons who are under expectations of benefit, by being employed on a work requiring several years to complete, I subjoin the estimate of Mssrs. Douglass and Martineau, of the cost of the whole

work. Douglass states the total at $4,558,725. Martineau makes the cost $3,742,693. This is about one third the actual cost; although the gentlemen were requested to hide nothing from the public, but to make a full estimate, it order that there might be no blame resting on the Commissioners, under whose responsibility the work was to be performed."

15 For a fuller treatment of the opposition of Westchester residents to the aqueduct, see Blake, Water for the Cities, pp. 148-151.

16 Since New York City's ordinary expenses at the time amounted to only 1-1/4 million dollars per year, it is not hard to understand why the aqueduct seemed very expensive indeed. (Reminiscences of JBJ, p. 132.)

17 Jervis, "Report to the Board of Water Commissioners," December 27, 1836, Jervis Papers.

18 Ibid.

19 Doc. No. 44, p. 430.

20 Reminiscences of JBJ, pp. 159-162.

21 Jervis, "Report to W.C.," December 27, 1836.

22 Reminiscences of JBJ, p. 162.

23 See Tower, pp. 89-90. Also T. Schramke, Description of the New-York Croton Aqueduct in English, German, and French (New York, 1846), pp. 28-29.

24 Jervis, "Report on Sing-Sing Kill Aqueduct Bridge," February 8, 1837, Jervis Papers.

25 Acts of the Legislature. . .Croton Water, p. 14.

26 Reminiscences of JBJ, p. 128.

27 Jervis, "Report on Sing-Sing," February 8, 1837.

28 Ibid.

29 Jervis' method of bolting together cast iron plates did not allow for expansion and contraction with changes in temperature. He later admitted that he should have used large iron pipes with faucet and spigot joints. (Reminiscences of JBJ, p. 128.)

[30]Carl B. Condit, American Building (Chicago, 1968), p. 73. Also see FitzSimons' "Introduction" to Reminiscences of JBJ, p. 11.

[31]See Jervis, "Specifications of the manner of constructing an Aqueduct Bridge across the Valley of Sing-Sing Kill," April 1837, Jervis Papers.

[32]Jervis, "Report on Croton Dam," February 13, 1837, Jervis Papers.

[33]Ibid.

[34]The microfilmed Papers of JBJ include a "Report on Croton Dam," dated 13 February 1837. This draft report, addressed to the Water Commissioners, outlines what this author has called Jervis' first plan for Croton Dam. His second plan, ultimately adopted, is found in a "JBJ Report Book." This bound volume of manuscripts contains "Report No. 6 Relating to the Dam at the head of the Aqueduct." The bound report is also dated 13 February 1837. The second plan obviously went to the Water Commissioner for approval. It is not known if Jervis ever officially presented them with his first design as an alternative.

[35]Jervis, "Report on Croton Dam," February 13, 1837.

[36]Ibid.

[37]Ibid.

[38]Jervis, "Croton Aqueduct--Specifications of the manner of building a Dam across Croton River," April 1837, Jervis Papers.

[39]Because he lowered the aqueduct's entrance, Jervis had to adjust the declivity of its line. Instead of adjusting the entire line, he chose to reduce the declivity along its first five miles, reducing it from 13-1/4 inches to 7.15 inches per mile. To compensate for this reduction, along this stretch of line Jervis increased the height of the conduit so it could carry more water.

[40]Jervis, "Specifications of the ... Dam across Croton River," April, 1837.

[41]Jervis, "Report to N. Y. Water Commissioners," February 16, 1837, Jervis Papers.

[42]At the time of this report, Jervis anticipated that no tunnels would be cut through earth. This situation was encountered, however, so Jervis later designed a cross-section for the conduit appropriate for tunnel cuts in earth. The cross-section is shown in Plate XX, Figure 4. (Note how he put the side walls under compression.)

[43]Wegmann, Conveyance and Distribution of Water, p. 247.

[44]Jervis, "Plans for Ventilators and Waste Weirs," February 25, 1837, Jervis Papers.

[45]Ibid.

[46]Ibid.

[47]Ibid.

[48]Jervis, "Monthly Report," Feburary 28, 1837, Jervis Papers.

[49]"Semi-Annual Report of the Water Commissioners, January 1 to June 30, 1837," Board of Aldermen Document No. 14 (New York, July 3, 1837), p. 92. Also see "Croton Aqueduct--Notice," February 28, 1837, Jervis Papers.

CHAPTER FIVE

Jervis had laid off two-thirds of his department for the winter, including all axemen and rodmen and several lesser-skilled assistants. So he had only five men to help him let contracts. Edmund French and M.O. Davidson worked out of an office in Sing-Sing. In the New York office, Henry Anthony, A.B. Lansing and T.J. Carmichael labored beside the Chief Engineer. None of the men wanted for work.

To get ready for contracts, Jervis split the aqueduct's long line into manageable units.[1] He cut the line into four "divisions," each roughly 10 miles long. He subdivided these into "sections," generally four- to five-tenths of a mile long, which contractors bid on. Under this plan, the line between the dam and Sing-Sing became the aqueduct's 1st Division, which Jervis cut into 23 sections. The sections did not have arbitrary boundaries; the Chief Engineer arranged them in a manner "most Convenient for the prosecution of the work." Jervis took particular care to see that no boundary cut across a major structure. He did not want two contractors working on opposite ends of a tunnel, bridge, or tall embankment.

In Sing-Sing, French and Davidson prepared a special map and profile of the 1st Division that contractors could study while preparing their proposals. Jervis informed his assistants that the map should delineate the boundaries of the 23 sections, and that: "On each section, there should be a brief description of the soil on the line, of quarries of stone in the vicinity, and any other circumstances that may not be apparent on viewing the map and profile."[2] Since contractors would be interested in the accessibility of various sections, French and Davidson located all public and private roads that intersected or passed near the line. While doing this, they learned that some sections were not very accessible at all, so French began negotiating with land owners for the right to build temporary roads across their properties.

In the New York office, Anthony, Lansing and Carmichael prepared final sets of working drawings. When not at drafting boards, they were busy "making detailed calculations of the several kinds of work" to be found in each section. They used the plans, geological reports, and a profile of the line to estimate the total amount of earth and stone to be excavated along each section; the cubic yardage of stone to be laid in walls and culverts; the amount of earth needed for embankments and backfilling; the cubic yardage of brick and stone needed for the conduit's interior, and so on.

Jervis, meanwhile, prepared specifications to supplement the working drawings. Besides describing structures -- giving their materials, dimensions, and shapes -- the specifications established construction procedures that contractors would have to follow. To cover the 1st Division, Jervis wrote three specifications: one for general work, one for Croton Dam, and one for Sing-Sing Kill Aqueduct Bridge. In his "SPECIFICATIONS of the manner of constructing the general work for the Croton Aqueduct," Jervis told contractors how the following work would be done:

grubbing and clearing timber
excavating earth and rock
tunnelling in earth and rock
laying masonry for culverts
laying foundation walls
embanking earth

laying protection walls
laying masonry for the conduit
back-filling
constructing ventilators and waste weirs.

The specifications were detailed for their time. Jervis specified the minimum dimensions of the stone to be used in different works, whether it was to be rubble, hammer-dressed, or cut. He also specified the maximum thickness of mortar joints. A quotation regarding cement demonstrates the control the Chief Engineer intended to exert over the contractors:

> Cement -- To be used either in mortar or grout, shall be composed of the best quality hydraulic lime, that has not been manufactured more than two months previous to the time of using, and clean sharp sand, in such proportions, and made in such manner, as may be required by the said Engineer. If sand is not obtained from natural beds or banks of sufficient purity, it shall be screened and washed, until all loam, gravel, or other improper matter, is wholly removed; and then dried before it is used. The hydraulic lime may be inspected at the place of manufactory, by a person or persons duly authorized by the said Water Commissioners. It shall be transported from the place of manufactory, to the place where it is to be used, in tight casks, that will effectually prevent its injury from water; and no lime shall be used, that has been wet, or in any way damaged; nor until it shall have been tried and approved by the said Engineer, or some person under his direction. To guard against disappointment in the quality of hydraulic lime, two sheds shall be erected to protect the casks containing the lime from the weather, and the lime used from them alternately, after the said Engineer shall have ascertained, from trial, that the same is good. [3]

To accompany the three specifications, Jervis prepared three "Proposition" or bid forms.[4] On these forms a contractor noted the rate of compensation he required for each type of work on a given section. Assuming that a contractor's bid was accepted, his rates of compensation were incorporated into the "Articles of Agreement" concluded between the contractor and the Water Commissioners.

Jervis, apparently with no help from a lawyer, wrote the "Articles of Agreement." His contract stipulated more than just the compensation a contractor would receive. It required the contractor to furnish materials, which were to be "of a sound, durable and good quality, and approved by the Chief Engineer." The contractor could not subcontract work, except the delivery of materials, and he had to construct his section "in the most substantial and workman-like manner" and in strict accordance with the specifications. But if Jervis directed any "alterations in the [aqueduct's] form, dimensions, or materials," the contractor had to adopt the Chief Engineer's changes. If a contractor neglected his work, or performed it improperly, Jervis could certify this in writing to the Water Commissioners, and they could declare the contract violated and abandoned.

Among other provisions, the contract stipulated that hydraulic masonry, to assure its soundness, could be laid up only "between the 1st of April and the 15th of October, and at no other season," unless Jervis allowed otherwise. Usually, a contractor was to finish his section in three years. During that time he and his men were to remain sober and to interfere as little as possible with the lives of Westchester County residents:

> No public or private road . . . shall be obstructed by excavation or otherwise until direction shall be given by the said Chief Engineer to complete the aqueduct across said road or highway; nor shall any crops of grain, grass, or vegetables, nor fruit trees, nor any dwelling-house or other building on said line of aqueduct be disturbed, unless by direction of said Engineer.
>
> And it is further agreed by the said contractor that [he] will not allow any person in [his] employ to commit trespass on the premises in the vicinity of [his] work.
>
> And the said contractor further promise[s] and agree[s] that [he] will not . . . . give or sell any ardent spirits to [his] workmen, or any other person, on or near the line of said aqueduct, or allow any to be brought on the work by the laborers, or any other person; and will do all in [his] power to discountenance its use in the vicinity of the work. 6

On April 10, 1837 the engineers made available to contractors the maps and profiles, working drawings, and specification, proposition and contract forms. Until April 14, contractors examined these materials in New York. Then everyone moved to Sing-Sing so the contractors and engineers could study the aqueduct's line, its plans, and local stone quarries at the same time.[7] Sealed bids were originally due on April 24, but Jervis extended the deadline to April 26 to:

> accommodate the mechanics of this city [New York] whose information on this description of work, might not be as perfect as those who were accustomed to the execution of contracts on Canals, Railroads, and other large jobs. 8

There was no lack of interest on the part of contractors; Jervis received five to eight propositions for each section. The engineers spent long hours multiplying and adding in order to evaluate the propositions. When all the arithmetic was finished, it became clear that although contractors were anxious to undertake the work, they were also very concerned over its novelty, the high standards of workmanship demanded by Jervis, and the surprising scarcity of good stone along the line.[9] The bids ran higher than expected.

Jervis prepared a list of all bids and presented it to the Water Commissioners. Unfortunately, they received the bids while the nation was in the midst of an economic panic that had depressed the money market. New York's issue of the first one million dollars of Water Stock had sold well, at rates 12-1/2 per cent above par. But the market for Water Stock had collapsed, and the Commissioners found themselves with high bids and too little money.[10] Consequently, they could not put all the 1st Division under contract. After consulting with Jervis, the Commissioners contracted for only 13 of the division's

23 sections. In each instance they engaged the lowest bidder, if he was still willing to do the work. Nevertheless, "by the estimate of quantities, calculated at contract prices," Jervis figured that these 13 sections alone would cost $922,000.[11]

Early in May the contractors started erecting workers' shanties and opening local quarries. Laborers, far more than could be used at first, flooded in, and because other work was so scarce, many men offered to work only for their board.[12]

While the contractors readied themselves, Jervis brought his engineers up to strength. He had cut the line into four divisions, so he organized his engineers into four field teams, plus a central office staff. He put each team under the supervision of a Resident Engineer who lived and worked on his division. Under each Resident, Jervis called for at least one 1st Assistant Engineer, one 2nd Assistant, and "one or two rodmen . . . and one or two labourers, as the condition of the work may require."[13] Later, when construction had sufficiently progressed up to five skilled masons joined each team as inspectors of masonry. (See "Engineering Department Roster," Appendix III.)

The men laid-off over the winter returned to work. New recruits, such as Peter Hastie, James Renwick, Jr., and William Jervis, joined the department.[14] The Chief Engineer named Edmund French the 1st Division's Resident Engineer, and Henry Anthony assumed that role for the 2nd, the next to be put under contract. Since construction on the 3rd and 4th Divisions would not start for some time, Jervis temporarily combined them under the charge of Peter Hastie.

The Chief Engineer granted considerable authority to his Resident Engineers. His contract form stipulated that:

> In the case of the absence or inability to act, of the said Chief Engineer, the Resident Engineer having charge of the work embraced in this contract, shall have, and is hereby vested with all the powers herein given to the aforesaid Chief Engineer.

Since Jervis worked out of New York and toured the line only every week or two, the Resident Engineers had charge of the day-to-day affairs within their divisions. The Chief Engineer urged them to exercise their full authority as managers:

> The particular management of your Division is committed to your care, and in whatever relates to the execution of the works or the energy, the efficiency, and business-like deportment of the Engineer department, under your direction, you must consider yourself responsible; and the undersigned will not be wanting in releasing you from any embarrassments, that may arise from inattention on the part of your assistants to your directions. While it is recommended to pursue a courteous deportment and to avoid every reasonable cause of dissatisfaction on the part of your assistants, it is at the same time urged, that you do not sacrifice or allow the interest of the work to suffer, from a delicacy that tends in the least to insubordination, or delinquency in duty. [15]

The Resident Engineers' greatest responsibility was to understand thoroughly the aqueduct's plans and specifications and to check any contractor who deviated from them. Jervis provided his Residents with an efficient means of enforcing the plans and specifications; he gave them control over the contractors' purse-strings. Once a month from April to October, and once every two months during the winter, the Resident Engineers provided Jervis with estimates of the quantities of work done by the contractors. Jervis forwarded these estimates to the Water Commissioners, who paid the contractors accordingly. If a contractor's work was unsatisfactory, the Resident Engineer admonished him -- and withheld his estimate until all errors were corrected.

In late April and early May, Edmund French and his seven or eight assistants prepared the 13 sections for ground-breaking. They conducted careful levels, noting at 50-foot intervals how far above or below ground the aqueduct's grade line ran. They entered this information in field notebooks, and from it calculated the contents of required excavations or embankments.[16] Then they set stakes marking the extreme breadth of trenches and embankments. When this work was completed on a section, it was ready to be worked. On May 16, two years after the Water Commissioners had been authorized to build the aqueduct, but only seven months after John Jervis joined the project, contractors Young and Scott, working on Section 20, finally broke ground.

The engineers had worked hastily to ready the 1st Division for construction, and it did not take long for some problems to develop that were attributable to haste. A controversy quickly arose, for example, over Croton Dam. Jervis had designed the dam and let a contract on it, knowing only that it was to be located somewhere along the bluff rock below Garretson's Mill. He had not had a specific location for the dam because Edmund French's work of sounding the Croton's bed had been halted by winter weather. In May, June and early July, Jervis and French waited for the Croton to fall so they could examine its bed more readily. Finally, on July 31 they chose a site that was 400 feet downstream from the one Douglass had staked.

With a specific site in hand, the Chief Engineer once again redesigned the dam. Several of its "essential principles" remained unchanged, such as the profile of the main wall and the use of an apron, but Jervis modified the structure a great deal.[17] Bedrock across the channel proved so scarce that to keep the northern end of the dam on rock, Jervis had to shorten the weir from 100 to 90 feet. He also had to carry the southern end of the dam so far into the bluff that a 12-foot thick southern abutment was no longer necessary. The bluff, cut down and shaped, also served as part of the main wall.[18] Finally, stone masons no longer had to lay a gateway for the aqueduct. A tunnel cut through the bluff would serve as the aqueduct's entrance.

The contractors for Croton Dam -- Clark, Strover and Yates -- took exception to these changes. When they signed their contract, they expected to lay 13,000 cubic yards of masonry, at rates from $5.25 to $6.25 per cubic yard.[19] The modifications greatly reduced the masonry in the dam, so the contractors protested that they were going to be paid far less for their work than expected. They petitioned the Water Commissioners for redress. If they could not lay a full 13,000 cubic yards, then they wanted a higher rate of compensation for each cubic yard which they did lay.

Upon receipt of this petition, the Commissioners requested an opinion from Jervis, and they received one that typified his hard-nosed approach to business. Jervis said that he had told the contractors, before they submitted their bids, that this very site for the dam <u>might</u> be adopted and cause some changes in the dam's plans. Moreover, they had signed a contract that bound them to abide by any alterations specified by the Chief Engineer. Consequently, the contractors were not entitled to any extra compensation. If they maintained their protest, Jervis thought it best simply to declare their contract abandoned and to re-bid Croton Dam. The Water Commissioners did just that.[20]

Jervis ran into a similar problem at the site of the Sing-Sing Kill Bridge. From geological data provided by Edmund French, when Jervis designed the bridge he believed the abutments for the elliptical arch would stand on rock. But when contractors Young & Scott opened the ground, they discovered that rock was less extensive than supposed. To provide the abutments with the foundation that he wanted, Jervis had to increase the span of the arch from 80 to 88 feet.[21]

Another problem, an economic one, arose because of the unexpected paucity of good stone along the 1st Division. Jervis wrote the Water Commissioners that he had interpreted T. J. Carmichael's report on local quarries too optimistically:

> In examining for stone suitable for the various kinds of work on the Division offered for contract, I regret to say we have not been as successful, as from the partial examinations of last fall we had hoped to be.[22]

The engineers and contractors found too little stone in the region suitable for use in the conduit's interior, where it would be in constant contact with water. Because of this scarcity, Jervis had to abandon the idea of facing the conduit's side walls with stone and adopt, almost exclusively, sides faced with "hard burnt, weather brick, free from lime." Brick had one advantage; it made a smoother wall that presented less resistance to the flow of water. But this advantage was slight and did not compensate for the greater cost of brick.

Because he could not have the less expensive stone facing, and because contractors' bids had run higher than expected, Jervis decided to reduce the conduit's cost by paring more materials. In the summer of 1837 he altered the conduit's specifications. The conduit's interior dimensions remained the same, but Jervis cut the depth of brick in the bottom and sides from 8 inches to 4 inches, and he reduced the thickness of the top arch from 12 to 8 inches. Altogether, he reduced the amount of brick per linear foot by 6-1/4 cubic feet, and the amount of stone and concrete by almost 4 cubic feet. Jervis knew there was some risk involved in this paring of materials, but he was "of the opinion the reduction thus proposed may with safety be adopted on three quarters of the line." Certainly the reduction was a significant cost-saver. He informed the Water Commissioners that: "At the prices usually paid, this would make a difference of about half a million dollars over 35 miles of aqueduct."[23]

Between ground-breaking and the completion of the aqueduct, the engineers had to cope not only with redesign problems, but with a whole range of problems seemingly inherent in such a large work. Contractors had trouble laying the conduit across marshy ground; its concrete foundation kept cracking. A 60-foot stretch of roofing arch fell in one day for no apparent reason. Careless contractors, blasting in rock, raised the hackles of Westchester residents whose homes were struck by flying debris. Shipments of hydraulic cement, upon testing, proved incapable of setting under water.[24]

Contractors often protested that the Resident Engineers' monthly estimates of completed work were too low. The Resident Engineers protested that some contractors required constant prodding to make them heed the specifications, and others attempted to back-fill over the masonry before it could be inspected. This was one practice that the engineers could not tolerate at all, because, as Jervis reported to the Water Commissioners, a close inspection of all masonry was absolutely essential:

> The works of ordinary masonry are generally laid up with mortar beds and joints that are imperfect, having the wall fair on the outside, and with numerous cavities in the interior. This method is entirely unfit for hydraulic masonry; but the workmen become so attached to it, that great vigilance is necessary to obtain that character of work which is indispensible for the aqueduct masonry. At first, the contractors and their workmen did not appear, in many instances, to understand the importance or practicability of complying with the directions given; this difficulty was surmounted, and they were left with no excuse for imperfect work. But experience has shown, that if we will have the work properly executed, there must be no abatement in the inspection of the materials and workmanship.[25]

One contractor laid a stretch of conduit on a Sunday, when no engineers or inspectors were working. Upon discovering this, the Resident Engineer insisted that the work come down. The contractor appealed to the Water Commissioners, stating that the Sunday work had not been a deliberate attempt to slip anything past the engineers. Besides, he had not even known that his men were going to work that Sunday. The Commissioners sought out Jervis' opinion, and he backed his Resident Engineer: the work had to come down. The Chief Engineer also opined that if the contractor's men had indeed done the work without his knowledge, then instead of looking for any compensation from the Commissioners, he should sue his own employees for the cost of the wasted materials.

While Jervis enforced inspection upon the contractors, neither he nor his Resident Engineers could enforce a code of conduct on the laborers who slept in shanties after working all day for little money at back-breaking tasks. At the peak of construction, nearly four thousand men toiled along the line. Most were Irish immigrants, newly arrived in this country, men who cared little for a contract which forbade them "ardent spirits."

The laborers were hearty, hungry and thirsty. Or as some Westchester resident characterized them, they were noisy, riotous and drunken. They stole fruits and vegetables and made it "unsafe and imprudent for a respectable female to walk on, or near, or along" the aqueduct.[26] Although many laborers initially had been glad to find any work at all on the aqueduct, they soon came to chafe at the bit of their difficult existence. Occasionally they rebelled, interrupting work on the line. One such rebellion occurred during the first summer's construction, as reported in the Westchester Spy on August 30, 1837:

> The laborers on the New York Aqueduct at Croton, a few miles above Sing-Sing, made a strike for higher wages a few days since. They had received, heretofore, about 70¢ per day, which they found insufficient for their support. The contractors objecting to advance their wages, about 300 refused to work. A few however remained at the lower rates, which displeasing the others, a general fight ensued. Information of the row was communicated to the inhabitants of Sing-Sing, where the military was ordered out, and several of the citizens armed themselves and marched to the scene of the action, but before they arrived there the laborers had separated, and no further disturbance took place. Several individuals were much hurt. . .

In the spring of 1838, another labor revolt broke out on Section 15 near Sing-Sing. During the winter, when there was less work and the demand for laborers was low, the contractor for Section 15 had paid unskilled men only 68-1/2 to 75 cents per day. When the contractor posted his pay schedule for April, he offered 75 to 81-1/4 cents per day, instead of the 87-1/2 to 100 cents that his men wanted. Denied and angry, the laborers started marching north towards the Croton Dam, picking up other men along the way before the magistrates of Mount Pleasant stopped them.[27] At about the same time as this strike, a riot broke out between the "Corkites" and the "Formanaghs," men from different counties in Ireland: "The fight was most desperate, resulting in broken heads, and maimed bodies and limbs, and eventually in the death of one of their countrymen."[28]

The Water Commissioners did not condemn the laborers for these outbursts. They condemned the opportunistic Westchester residents who had converted their farmhouses into taverns. Despite the contractual ban on liquor, a "love of lucre" had

> induced certain individuals, regardless of the injury inflicted on others, to open places of resort for the laborers where this <u>enemy of man</u> may be obtained, in any quantity for money. 29

John Jervis joined the Commissioners in regretting the easy availability of this "enemy of man" along the aqueduct. But while Jervis was religious, he was neither puritanical nor unrealistic. He had written a contract which forbade liquor and required contractors to keep a check on their men, but when taverns and labor unrest sprang up, Jervis was not surprised. He recognized that he was a civil, not a social engineer, and that some unpleasant realities, such as wild-cat strikes, could not be avoided. Put in another way, Jervis was unflappable:

> The usual wages now paid is 87-1/2 cents per day for common labourers, and 1.50 Dollars for masons. Controversies between the contractors and their men in relation to wages are very common on public works, and we cannot expect to be exempt from them on the line of the aqueduct.[30]

Despite the problems involved in inaugurating work on the aqueduct when Jervis reviewed the first summer's progress on the 1st Division, he was pleased. Perhaps contractors had not moved as fast as he would have liked, but the work had gone well:

> We have had an opportunity of seeing specimens of nearly all the several kinds of work given for the aqueduct; and after having given the subject the most careful consideration I see no important variation to propose . . . in relation to the plans or the character of the structures; and it affords me great pleasure to say, that I feel entire confidence in its stability and permanence, and its efficiency in answering the great object for which it is intended.[31]

The 1st Division, of course, represented only a fraction of the aqueduct's line. So while Edmund French's engineering party had worked the sections there, the rest of the engineers had forged ahead with the work that had to be done on the line from Sing-Sing to central Manhattan.

NOTES -- CHAPTER FIVE

1 Jervis, "Report to Water Commissioners," January 31, 1837, Jervis Papers. Also see Document No. 14, pp. 95-96.

2 Jervis, "Report to W.C.," January 31, 1837.

3 Jervis, "SPECIFICATIONS of the manner of constructing the general work for the Croton Aqueduct," April, 1837, Jervis Papers.

4 Examples of the "Proposition" forms for general work, Croton Dam, and Sing-Sing Kill Bridge are found in the Jervis Papers.

5 Jervis, "Croton Aqueduct -- Articles of Agreement," April, 1837, Jervis Papers.

6 Ibid.

7 Jervis, "Monthly Report," April 29, 1837, Jervis Papers.

8 Document No. 14, p. 92.

9 Reminiscences of JBJ, pp. 123-124.

10 Document No. 14, pp. 92-94.

11 Jervis, "Monthly Report," April 29, 1837, and "Result of letting: April 26, 1837," Jervis Papers.

12 Jervis, "Monthly Report," June 30, 1837, Jervis Papers.

13 Jervis, "Report to W.C.," January 31, 1837.

14 Jervis to Board of Water Commissioners, April 15, 1837, Jervis Letter Book.

15 Jervis, "Circular to Resident Engineers," May 30, 1837, Jervis Papers.

16 In a sense, French's team was repeating work that had been done before, but they were doing it more carefully. They were actually measuring the work that constractors would do, instead of just estimating.

17 Jervis, "Report in relation to Clark, Yates & Co.," August 31, 1837, Jervis Papers.

18 Jervis, "Croton Dam Specifications at letting of 6th November," Jervis Papers.

19 Jervis, "Report in Relation to Clark, Yates & Co."

20 See Water Commissioners, "Resolution." September 12, 1837; "Croton Dam Notice," October 3, 1837; and Jervis, "Abstract of Proposals at letting of 6th November 1837," Jervis Papers.

21 Jervis, "Monthly Reports," July 31 and August 31, 1837, and "Report in relation to the claims of Young & Scott," October 13, 1837, Jervis Papers.

At the same time he changed the span of the arch, Jervis added the hollow spaced seen in the bridge's parapet walls. The spaces were to help insulate the aqueduct, and also to help drain any moisture out of the structure. R. F. Lord, an engineer on the Delaware and Hudson Cànal, suggested the idea of the hollow spaces to Jervis.

22 Jervis, "Monthly Report," April 29, 1837.

23 Jervis, "Report Proposing Variation in Masonry of Croton Aqueduct," August 12, 1837, Jervis Papers.

24 An example of this problem is found in William Jervis to John Jervis, March 30, 1839, Jervis Papers: "A cargo of cement delivered on the line to several constractors--from a new manufactory--(Taylor and Little)--I have tested samples out of about 20 barrels--and not more than half would set in water after two hours--some of the balls fell to pieces after standing four hours. . ."

25 Jervis, "Report on the progress and condition of the Work on the Croton Aqueduct," December 26, 1838, Jervis Papers.

26 Quoted from Blake, Water for the Cities, p. 149.

27 "Semi-Annual Report of the Water Commissioners, January 1 to June 30, 1838," Board of Aldermen Document No. 5, (New York, July 2, 1838), p. 57.

28 Ibid., p. 59.

29 Ibid., p. 58.

30 Jervis, General Report," May 22, 1838, Jervis Papers.

31 Jervis, "Report for October and November," November 30, 1837, Jervis Papers.

CHAPTER SIX

The engineering department took no break after letting contracts on the 1st Division. Before gound was broken there, Jervis turned his attention towards the rest of the line, where most of the difficult engineering problems lay.

H.T. Anthony's field party worked the 12-mile-long 2nd Division. They set stakes, located access roads, sampled the soil, prepared maps and profiles, and estimated the quantities of different types of work that were needed. Peter Hastie's team started work on Manhattan. Major Douglass had located the two reservoirs there, but he had never run a final line from the Harlem River to the reservoirs. Hastie searched for the best route, one adapted to natural ground levels and to Manhattan's street plan, which had already been drawn up for the northern part of the island, even though the region was still sparsely settled:

> Mr. Hastie is prosecuting the surveys of the Island, which on account of the importance of avoiding, as far as practicable, interference with the arrangements and grade of streets, requires a very minute examination.[1]

Besides working on Manhattan, Hastie's men re-examined the southern part of the line in Westchester County. They altered it slightly in a few locations, and then restaked its center-line. T.J. Carmichael, meanwhile, hired six temporary laborers, rented small boats, and started taking soundings of the Harlem River's bed about a mile north of McComb's Dam, hoping to find a line of rock clear across the channel.[2]

Throughout the summer of 1837, Jervis had several tasks of his own, besides overseeing the 1st Division. That division's specifications for general work covered most of the structures needed on the 2nd, 3rd, and 4th Divisions, but the Chief Engineer still had to design a number of specialized structures. To prepare for this work, he continued to read about water-supply systems. He studied several articles in encyclopaedias and engineering dictionaries. He read William Matthew's Hydraulia: An Historical and Descriptive Account of the Water-Works of London, and the Contrivances for Supplying Other Great Cities (London, 1835). To supplement Hydraulia, Jervis obtained a series of reports on the London water works that had been printed by order of the House of Commons between 1821 and 1834.[3]

Jervis also became familiar with hydraulic works on this side of the Atlantic. He studied Philadelphia's Fairmount Works and read the annual reports published by the city's Watering Committee. He studied articles in Engineer and Architect's Journal which described the Alexandria Aqueduct Bridge being built across the Potomac at Georgetown. When it came to these American works, Jervis was not content to avail himself only of the literature. In May 1837 he visited Philadelphia and spoke with Frederick Graff, Fairmount's superintendent. In September he examined the Alexandria Aqueduct Bridge and interviewed Captain Turnbull, its engineer.[4]

In studying other works, Jervis was not searching for a panacea to solve all his technical problems. Virtually all the works he investigated were on the whole far different from the Croton Aqueduct.

Philadelphia, for example, used water-driven pumping engines, not gravity, to fill its reservoirs. And the Alexandria Aqueduct Bridge fell along a transportation canal, not a water-supply system. But in researching these works, Jervis thought he could find particular details, small pieces of technology, that he could transfer to the Croton Aqueduct.

Wherever the Chief Engineer saw a potential problem, he sought out a tried and practicable solution. When he interviewed Captain Turnbull at Georgetown, Jervis inquired into the system of coffer dams used in bridging the Potomac, because he had his own large river to cross--the Harlem.[5] In Philadelphia, he was interested in the city's experiences with large iron pipes, because he thought he might use pipe along certain parts of the line from the Harlem River on in. He wanted to discuss the relationships between water pressure, inside diameter, and wall thickness. He wanted to discover just how durable cast iron pipe really was. In the company of Frederick Graff, he also examined Philadelphia's reservoirs:

> Mr. Graff devoted several hours to explanations, and answers to questions, which he seemed to enjoy as a pleasure and which his practical familiarity rendered highly interesting.[6]

By August 8, 1837, Henry Anthony's team had completed preparatory work on the 2nd Division, and the Water Commissioners had accumulated sufficient monies to let additional contracts. The Chief Engineer and the Commissioners published a notice that the remaining ten sections in the 1st Division, and sections 24 through 53, or all of the 2nd Division, were ready for contractors to examine. Jervis accepted proposals until September 5, and again he received a number of bids, from eight to sixteen, for each section. The Commissioners let contracts on the remainder of the 1st Division that amounted to $695,000; the contracts for the thirty sections in the 2nd Division amounted to $1,237,000.[7]

Within the 2nd Division, Mill River, running in Sleepy Hollow just outside Tarrytown, posed the greatest natural obstacle. The deep part of the hollow ran for approximately 300 feet, and Mill River's bed fell to 72 feet below grade. Major Douglass had intended to cross Mill River with a bridge having five 70-foot arches. When Jervis first examined the site, he also thought a bridge was needed:

> The great elevation of the grade line above the bottom of the valley, and the fact that a stone bridge had been proposed [by Douglass]. . . had given me an impression in favor of a bridge. Accordingly, I had a plan made for a stone bridge, with 5 arches, each of 60 feet span, and an estimate made of the probable cost of the work. It appeared probable that a bridge with 60 feet arches. . .would be the most economical.[8]

The Chief Engineer estimated that a 5-arch bridge would cost $142,700. To test its economy, he calculated the cost of a 6-arch bridge with reduced spans of 50 feet. As it turned out, he thought the second bridge would cost in the neighborhoood of $140,000, or slightly less than the first. But because he was wary of aqueduct bridges, Jervis next estimated the cost of crossing the hollow with an embankment having a double culvert (two arches of 16 feet) to accommodate Mill River. The Chief Engineer arrived at a figure of only $97,000 for the embankment, so he dispensed with the idea of a bridge at this site. (To see how Jervis estimated the costs of these structures, see Appendix IV).

In two respects, Jervis little regretted his decision to go with an embankment. First, it was significantly cheaper, by some $43,000. Secondly, he believed an embankment less difficult to construct and less susceptible to settlement, frost, and other "contingencies that ultimately may derange, or impair the uniform efficiency of the aqueduct." Yet in one respect Jervis did regret his decision; a bridge would have been "a much superior work, in point of architectural beauty."

One part of Jervis, the pragmatic engineer, wanted an embankment for the sake of economy and stability. Another part of him, the proud engineer-architect, wanted the esthetic over the utilitarian structure. As almost always happened on the Croton project, the pragmatic engineer won out, due in part to Mill River's isolated location. Few people would ever see the aqueduct here, tucked away in a wooded Sleepy Hollow:

> The location does not appear to me, one that would justify the extra cost of a bridge merely to improve the architectural appearance of the work.[9]

Jervis, no doubt for the sake of economy, ultimately chose to channel Mill River through a single, 25-foot culvert under the embankment, instead of a double one. Mill River Culvert, attracted the attention of Washington Irving while it was under construction. The aqueduct passed right by his Sunnyside residence, and Irving watched over the work and talked with Henry Anthony and his assistant engineers. The author used Mill River Culvert as the subject on a fanciful tale that he spun out in 1840:

We have nothing new in these parts excepting that there has been the devil to pay of late in Sleepy Hollow: a circumstance by the bye, with which you of New York have some concern, as it is connected with your Croton Aqueduct. This work traverses a thick wood about the lower part of the hollow, not far from the old Dutch haunted church, and in the heart of the wood an immense culvert of stone arch is thrown across the wizard stream of Pocantico [Mill River], to support the Aqueduct. As the arch is unfinished, a colony of Patlanders [Irishmen] have been encamped about this place all winter, forming a kind of Pat-sylvania in the midst of a "witherness." Now whether it is that they have heard the old traditionary stories about the hollow, which, all fanciful fabling and idle scribbling apart, is really one of the most haunted places in this part of the country; or whether the goblins of the Hollow, accustomed only to tolerate the neighborhood of the old Dutch families have resented this intrusion into their solitudes by strangers of an unknown tongue, certain it is that the poor paddys have been most grievously harried for some time past, by all kind of apparitions. A wagon road cut through the woods and leading from their encampment has been especially beset by foul fiends, and the worthy patlanders on their way home at night have beheld misshapen monsters whisking about their paths, sometimes resembling men, sometimes hogs, sometimes horses, but invariably <u>without heads</u>, which shows that they must be lineal descendents of the old goblin of the Hollow. These imps of darkness have grown more and more vexatious in their pranks; some occasionally tripping up, or knocking down the unlucky object of their hostility. In a word, the whole wood has become such a scene of <u>spuking</u> [spooking?] <u>and diablerie</u>, that the paddys will not any longer venture out of their shantys at night, and a whiskey shop in the neighboring village, where they used to hold their evening gatherings, has become obligued to shut up for want of customers. This is a true story and you may account for it as you please. The Corporation of you city should look into it, for if this harrying continues I should not be surprised if the Paddies, tired of being cut off from their whiskey, should entirely abandon the goblin region of Sleepy Hollow, and the completion of the Croton Water Works be seriously retarded.[10]

Happily, no goblins interfered with the Irishmen who worked on Jewells Brook Culvert near Irvington, the second largest structure in Henry Anthony's division. Jervis engineered Jewells Brook Culvert, which he called "one of the most arduous undertakings on the line," to solve three basic problems. First, it maintained the aqueduct's grade by supporting the base of the conduit some 50 feet above ground. Secondly, it allowed Jewells Brook free passage. Thirdly, "at heavy expense" it spanned a country road that could not be relocated.

To build this culvert, laborers cleared all timber, vegetable matter, and loose, spongy earth from the valley floor. Then they prepared the foundations for the 6-foot culvert and the 14-foot road arch. After turning the culvert and road arch, they began laying the conduit's dry foundation wall. While raising that wall, they simultaneously carried up the contiguous earthen embankment, flanked with stone. At all times they kept the earthen embankment at least two feet below the wall, so inspectors could examine how the wall was being laid. When the wall reached the requisite height, it was capped with a layer of concrete. Skilled masons then laid the conduit, and when they were finished, laborers carried earth up and over the top arch.

The stepped, stone buttresses seen at the base of the embankment were not in the original plans. After some particularly tall embankments had been completed, such as this one and the one at Mill River, Jervis and his Resident Engineers recognized that buttresses were needed to prevent the embankments from sliding.

During the winter of 1837-38, whenever weather permitted, contractors along the first 21 miles of the line continued work. Although they could lay no hydraulic masonry, they cleared timber and brush, excavated, tunneled, built foundation walls, protection walls and embankments, and gathered materials for the upcoming spring.[11] William

Jervis, now Resident Engineer on the 3rd Division, prepared that part of the line for contract. The 3rd Division included yet another large embankment, with culverts and a road arch, for crossing the Sawmill River valley at Yonkers.

While William Jervis worked his division, Peter Hastie prepared the small portion of the 4th Division that lay north of Harlem River. John Jervis, meanwhile, assisted by Horatio Allen, his new Principal Assistant Engineer, tackled the most difficult stretch of the line, running from the northern bank of the Harlem River to the Distributing Reservoir on 42nd Street. T. J. Carmichael had sounded the Harlem's bed, and Hastie had routed the aqueduct on Manhattan. Now the Chief Engineer designed the structures falling along that line.

Jervis started with the problem of crossing the Harlem River. Its valley had a breadth of 1450 feet, measured along the aqueduct's grade line. Measured down from grade, the valley fell to a maximum depth of about 150 feet. Along the valley floor (composed of bed-rock, boulders, sand and mud) the river ran in a channel from 560 to 620 feet wide, depending on the tides. At mean tide, the river ran 118 feet below grade.

Major Douglass had intended to maintain the aqueduct's grade across the Harlem by constructing a high masonry bridge. John Martineau, while serving as a consultant in 1834-35, had suggested crossing the Harlem with a low masonry bridge supporting an inverted syphon of iron pipes. Ever since they had received Martineau's suggestion, the Water Commissioners had favored the inverted syphon plan, because it appeared much less expensive. Nevertheless, near the end of 1837 they still wanted to test the economy of Martineau's idea, so they instructed Jervis to provide them with two plans for the crossing: a high bridge and a low bridge.

In compliance with the Commissioner's instructions, on December 12 Jervis submitted his "Report in relation to the Plan for Crossing Harlem River."[12] The high bridge was to have sixteen semi-circular arches supported on piers. Seven of these piers stood in the river's channel, and the others stood on table land. The foundations of the river-bed piers rested 18 to 32 feet beneath the Harlem's surface at flood tide, and the height of the structure, from the lowest foundation to the top of the parapet walls, measured 163 feet.

In deriving this design, the Chief Engineer attempted to "effectually combine stability, permanence, symmetry and economy."[13] For Jervis, combining these qualities proved most difficult when selecting the arch spans. Without question he preferred small masonry arches on aqueduct bridges. He believed they were easier to construct and more permanent. Yet in designing this bridge, his preference for small arches had to yield, at least in part, to his desire to cross the Harlem with a bridge having as few piers as possible.

Because of the bridge's height, the piers would be very costly. Of even greater concern, a contractor would have a difficult time preparing their foundations. On the table land, about half the piers would stand on rock, but the others would have to stand on wooden piles driven deeply into sand and capped with concrete. Founding the river-bed piers would prove even more difficult. Jervis anticipated that all river piers would stand on rock, but in a sense that was a small consolation. To reach the rock, a contractor would have to erect a $14,000 coffer dam for each pier, evacuate up to 32 feet of water, and then remove a heavy layer of mud or sand from the river's bottom.

To demonstrate the feasibility of sinking piers in the Harlem River, Jervis informed the Water Commissioners that:

> Works of this kind have recently been accomplished in this country. The rail road bridge over the Schuylkill, near Philadelphia, had one of its piers on a hydraulic foundation of 29 feet deep; and the foundations of several of the piers. . . for the Potomac Aqueduct, have been put down in 28 to 35 feet [of] water, under the direction of Capt. Turnbull, of the U. S. Engineers, which shows the practicability of executing such works.

After assuring the Commissioners of the feasibility of sinking piers in a deep river, Jervis immediately warned them of uncertainties:

> At the same time, a history of their progress also shows that there is much contingency in their execution, and we are thereby admonished to make large estimates for similar work.[14]

After weighing the merits of small arches against the merits of fewer piers, Jervis chose smallish 50-foot arches over the table land. The piers supporting these arches would be shorter and easier to construct, so he could make do with more of them. Over the river, he chose larger arches spanning 80 feet, and a consequent reduction in the number of piers. Between the arcades of 80- and 50-foot arches, Jervis specified one 70- and one 60-foot arch. These two "transitional" arches presumably were to improve the structure's symmetry and balance. They muted the contrast between the river and table land arcades.

The Chief Engineer's high bridge carried several unusual internal features. Jervis intended to construct the piers under the 50-foot arches of solid hydraulic masonry, but he left hollow spaces in all the others:

> The piers for the large arches, from their great height, should be constructed hollow, in order to ensure stability, at least expense. A greater width of pier is required to give support to the arch, and resist its horizontal thrust, than is required to bear the vertical weight of the super-incumbent mass. In ordinary cases, particularly for arches of small span, it is the usual practice to give the proper breadth of pier, by filling the interior with rubble masonry, only dressing the face stone. But in piers of great height, designed for arches of large span, this method is not advisable, for the following reasons:
> The interior masonry not being dressed as well as the exterior, is liable to settle more, and eventually force the face stone to bulge outward, and injure, it if does not destroy the work. A second reason is, the tendency that a large mass of masonry has to prevent the uniform and early hardening of the cement. [15]

The high bridge shared other internal features with the Sing-Sing Kill Aqueduct Bridge. Jervis lined the conduit over the bridge with cast iron plates. To guard the conduit against frost and to help drain any moisture out of the masonry, he left insulating, hollow spaces in the parapet walls. Finally, he reduced the dead-load on each arch by using interior spandrel walls, instead of a solid fill over the arch barrel.[16] All things considered, the high bridge represented a great engineering challenge to John Jervis, one that would not come cheaply. He estimated it would cost $935,745.

Jervis next considered crossing the Harlem with iron pipes supported on a low masonry bridge that would not maintain the aqueduct's grade line. This structure took the misleading name of "inverted syphon" or "syphon bridge" because its pipes resembled the bent tube of a syphon, turned upside down. It would not, however, function in the manner of a true syphon:

> It is called an "inverted syphon." The term has no doubt been given for convenience. . . .At the same time it should be borne in mind . . ., [that its iron pipes] have nothing of the <u>peculiar</u> principle of the syphon. In their action, they are simply pipes, through which the water flows by the well known principles of hydraulics, which are the same that will operate in its distribution through the city.[17]

The standing water in an elevated reservoir creates a pressure that forces the fluid through a city's mains or distributing pipes. In the same fashion, the water in the cast iron pipes on the descending side of the syphon bridge would create a pressure causing the water to rise in the iron pipes on the ascending side of the bridge. Unlike the water in the masonry conduit, moved by gravity, the water crossing the syphon bridge would totally fill the pipes and flow under pressure.

To design the low bridge, the Chief Engineer first had to determine how many pipes of what size were needed. Jervis believed the masonry conduit could deliver up to 60 million gallons of water daily to the Harlem River. The inverted syphon had to be able to carry all that water across to Manhattan. He began with the idea of laying just one large pipe, but he finally decided to use multiple pipelines, each 36 inches in diameter:

> The width of the bridge must depend on the width required for the pipes; and this again, will depend on the diameter of the pipes. A single pipe, sufficiently large to carry the whole quantity of water, would be accommodated on the most narrow bridge. There are, however, objections to this: a single pipe would place the successful action of the aqueduct on its good condition; consequently, interruption would be involved in any necessary repairs; which it is important to avoid, by every reasonable means in our power; and very large pipes would be more liable to imperfections than smaller ones. Water pipes of cast

> iron have not, that I am aware of, been larger than three feet in diameter. The principal iron mains, in the water works of London, are of this size; and the same are used in a part of the water works of the City of Glasgow, in Scotland. I can see no reason why this particular limit has been adopted, unless experience has decided it to be the most economical. There certainly can be nothing impracticable in going to four feet, so far as. . .the casting is concerned, for experience in casting cylinders for steam engineers has demonstrated this; and were there any particular necessity for this dimension, I should have no fear that it might be successfully be accomplished. But in view of all the circumstances of the case under consideration, I have arrived at the conclusion, that three feet pipe will be most appropriate.[18]

Given the length and diameter of the pipelines, the depth to which they fell in crossing the valley, and the fact that Jervis terminated them some 28 inches below their start, hydraulic formulae predicted that each 36-inch pipe would discharge approximately 15 million U. S. gallons daily.[19] Consequently, Jervis made the bridge wide enough to handle the four pipes needed to transport the desired 60 million gallons per day to Manhattan. But as a cost-cutting measure, he recommended that only two pipelines be laid at first, because their water discharge would "probably be sufficient for the next fifty years." The city could add the third and fourth pipes when needed.

Jervis commenced the pipes in an influent pipe chamber, where a rise and fall cast iron gate guarded the entrance to each pipe. The 9-foot-long pipe sections, generally having a wall thickness of one inch, descended into the valley on a foundation wall that closely followed the natural terrain. In the center of the valley the wall ran four feet above the Harlem at flood tide. Here Jervis located stopcocks and wasters that could be opened to wash accumulated sediment out of the lines. After passing this level stretch, the water began to rise towards Manhattan, passing over a semi-circular arch spanning 80 feet that rose 50 feet above flood tide. The water then passed over an arcade of three arches of 35, 30, and 25 feet. From the abutment of this arcade, the pipes again ran on a foundation wall until reaching an effluent pipe chamber, where the water reentered the masonry conduit.

Jervis estimated that the low bridge would cost $426,000--or a full half-million dollars less than a high bridge. Given such a savings, without reservation he recommended the inverted syphon:

> It appears the plan by pipes has largely the superiority in point of economy. In my opinion it will be fully as efficient. The pipes will decay, by the action of time, more rapidly than stone masonry, especially if the masonry can be kept from injury by frost. But as only two, or half the pipes, are required to be put down at present, it may be assumed that if the $66,000 saved by this, is invested at five per cent, it will produce a sum that will forever maintain the pipes, to the full extent that may be wanted. The high bridge will be more exposed to casualties that may, at some future period seriously interfere with the successful operation of the aqueduct. It is, however, greatly superior, in point of architectural magnificence, and maintains two feet greater elevation. These are the only two points of superiority that I have been able to discover, and can therefore have no hesitation in recommending the plan by pipes as decidedly the most appropriate.[20]

On December 27, fifteen days after reporting on Harlem River, Jervis submitted his "Report in relation to the Location of the Line of the Croton Aqueduct, from Harlem River to the Reservoirs."[21] This report, based on Peter Hastie's surveying work of the previous summer, was incomplete. The Chief Engineer had not had time to finish plans for all the large structures on Manhattan, especially the reservoirs. Jervis discussed in greatest detail the crossing of

Manhattan Valley, which he considered one of the "most formidable obstacles, in point of expense, on the line of the aqueduct."

The aqueduct encountered Manhattan Valley two-and-an-eighth miles below the Harlem River. This broad depression, 4180 feet wide, fell to 103 feet below grade. It had been supposed, by Douglass, the Water Commissioners, and for a while even by Jervis, that Manhattan Valley required an aqueduct bridge. Some persons, including a few of the Water Commissioners, wanted a bridge here, because it would have to be an impressive structure.[22] Jervis was not unaware of this santiment:

> The wish. . .has been expressed by many citizens, that the established inclination of the aqueduct should be maintained across this valley, on a bridge of substantial masonry, that would do credit to the architectural taste and enterprise of the city.[23]

Jervis knew he had disappointed the devotees of long arcades by opting for a low syphon bridge across the Harlem. Consequently, he perhaps felt some real pressure to placate the esthetes by constructing a monumental bridge across Manhattan Valley. But his careful examination of the site resulted in a predictable conclusion. A bridge would be too expensive, costing between $983,000 and $1,386,000.[24] So the Chief Engineer opted for a less expensive means of crossing the valley. He chose another inverted syphon.[25]

Jervis terminated the long 36-inch pipelines three feet below their start, and he calculated that four of them would discharge 45 million U.S. gallons daily.[26] This figure represented only three-fourths of the water that the syphon bridge would transport across the Harlem and onto Manhattan. This reduction was purposeful. New York's population was still clustered on southern Manhattan, and the Distributing Reservoir on 42nd Street would serve that part of the island. But the population was moving northward, and someday the entire island would be thickly settled. When that day arrived, Jervis believed that a reservoir, drawing a portion of the aqueduct's water, would be needed near Manhattan Valley. So from the valley southward, the Chief Engineer believed it unnecessary to maintain an aqueduct capable of discharging a full 60 million gallons per day.[27]

The major advantage of the inverted syphon at Manhattan Valley was its cost. Jervis estimated that two pipes could be laid for $304,000, and four pipes for $454,000. The structure's major disadvantage was its sacrifice of three feet of elevation over four-fifths of a mile. This compared unfavorably with the masonry conduit ahead of the inverted syphon, which fell only 13-1/4 inches per mile. Because the loss of any elevation along the line resulted in an equal loss of elevation for the city's future Distributing Reservoir, and therefore diminished the effectiveness of that structure, Jervis tried to keep such losses to a minimum.

In the case of Manhattan Valley, he was able to regain 8-1/2 inches of the elevation he lost over the inverted syphon's run. Because the masonry conduit south of Manhattan Valley would not have to deliver a full 60 million gallons daily, Jervis reduced its declivity:

> [We can] regain, in part, the elevation we lose by using pipes across the valley, by reducing the declivity in the aqueduct from the effluent pipe chamber to the receiving reservoir, from 13-1/4 inches to 9 inches per mile. This section of the aqueduct will dishcarge about 40 million imperial gallons per day.[28]

When Peter Hastie ran the aqueduct's line between Manhattan Valley and the Receiving Reservoir, he traversed a rural area. But the area's future had already been mapped out, and the map showed a grid of city streets that someday would cut rural acreage into city blocks. The streets were coming, and Hastie, Jervis and the Water Commissioners felt obliged to take them into account. Wherever possible, Hastie passed the conduit underground in this district, in order to avoid the construction of expensive road arches. He was quite successful in this effort, except at Clendenning Valley: 2,000 feet wide, in places 50 feet deep, and the future site of 96th through 101st Streets.

Because Clendenning Valley was not exceptionally deep, and because he wanted to sacrifice as little elevation as possible in crossing it, Jervis did not use another inverted syphon. He wanted to maintain the aqueduct's new declivity of only 9 inches per mile, so he designed an elevated structure to support the masonry conduit.

In Westchester County, the Chief Engineer had used massive embankments to cross depressions of comparable depth. But while that rough-looking construction sufficed in the "backwoods" of Westchester, Jervis thought it inappropriate for Clendenning Valley, which would someday be in the midst of a dense population. An embankment would consume too much valuable real estate on Manhattan, and its road culverts would not be "in accordance" with other street bridges in the city.[29] Jervis did not want the structure to be too bulky or plain; nor did he want it to be too ornate, too expensive, or too much of a threat to the stability of the aqueduct. In short, he did not want an arcade of masonry arches stretching for 2000 feet. After sorting out what he did not want, Jervis was left with a structure similar in many ways to the one he designed for the Sing-Sing Kill valley. Instead of designing one long aqueduct bridge, he opted for six small bridges connected by a foundation wall laid in mortar.[30]

On the city map, 96th was laid out to be a principal street, 100 feet wide; 97th through 101st Streets were to be 60 feet wide. Jervis accomodated 96th Street with two arches, each spanning 27 feet. For the other streets, he proposed a single arch of 30 feet. On each side of a carriage-way he located small arches for pedestrians. Even though the road bridges at Clendenning Valley were quite small, the Chief Engineer believed they needed protection from water leakage and frost, so he initiated the same safeguards he had used on the Sing-Sing Kill Bridge. He lined the conduit over the arches with cast iron, and he left hollow spaces in the parapet and interior spandrel walls.

Seven-eighths of a mile below Clendenning Valley, the aqueduct's line reached York Hill (in present-day Central Park), whose crest was roughly bounded by 6th and 7th Avenues and by 79th and 86 Streets. Major Douglass had selected York Hill as the site of the Receiving Reservoir, because it was the southernmost parcel of land on Manhattan that was both large enough and high enough for the massive structure. In his December 27th report to the Water Commissioners, Jervis concurred with Douglass' site selection, and he presented the rudiments of his reservoir design. The design was admittedly sketchy, because he had not had time "to mature and prepare definite plans." When the definite plans were readied a few months later, the Chief Engineer specified the Receiving Reservoir shown in the illustration. [31]

For a short time, Jervis considered eliminating this structure from the aqueduct's line. The reservoir's main purpose was to store water, up to 190 million U. S. gallons of water, but this water would be needed only if and when there was a suspension of the daily running supply provided by the aqueduct. In a sense, then, the Receiving Reservoir was not absolutely necessary. In deciding to go ahead with it, Jervis once again demonstrated his conservative, careful approach to engineering:

> should [the aqueduct]... be able to perform its office without interruption, very little storage would be required. But in a work of this magnitude, whatever might be the care and skill exhibited in its construction, it would not be prudent to hazard so important an interest to contingencies that no sagacity may now anticipate. [32]

Jervis fully believed that his designs guarded the Croton Aqueduct against structural failures, but he was wise and humble enough to recognize that failures might still occur. So he went ahead with the Receiving Reservoir, seeing it as yet another safeguard, an expensive one that would cost approximately $310,500. For this price, he happily received a few other benefits, besides safety. The water in the reservoir, through contact with air, would regain any freshness it might have lost in traveling 38 miles from Croton Dam. And through settlement, the water would lose impurities it had carried with it. Finally, when the city moved up north to surround the structure, it could serve as a distributing reservoir and deliver water to the neighboring community.

New York's Receiving Reservoir was certainly one of the largest structures of its kind in the world. Along the tops of its exterior walls, from outside edge to outside edge it measured 1,826 feet long and 836 feet wide.[33] The walls formed a perimeter which extended for over a mile. The structure covered seven city blocks, and the surface area of the water was 31 acres.

In designing the reservoir, Jervis took several potential dangers into account.[34] First, he was concerned that its long walls might burst under the pressure exerted by the standing water. To prohibit this type of failure, he enclosed the water within heavy earthen embankments which were flanked by stone protection walls. The embankments were 18 feet wide on the top and carried a slope of 1-1/2 horizontal to 1 vertical on the inside face, and a slope of 1 to 3 on the outside. Secondly, Jervis worried that water might leak through the walls and undercut the structure, so he made the central portion of each wall out of impervious, puddled earth. Thirdly, to prevent water from ever spilling out of the reservoir and eroding its walls, he incorporated a waste weir into his plan. Whenever the water rose to within four feet of the top of the reservoir, it would pass over a weir, fall into a well, and automatically discharge through a sewer.

Jervis believed these three basic security measures were sufficient to protect the reservoir, but he still worried: what if a failure occurred, despite these measures? The Chief Engineer wanted an extra measure of safety, and he gained it by dividing the reservoir into two compartments, a Northern and a Southern Division. The divisions were separated by a broad wall, and yet connected by a network of of pipes with stopcocks. Normally, the two divisions would function together. An open equalizing pipe set into the reservoir's dividing wall would cause them to share the same water level. Both would receive water from the masonry conduit, and both would discharge water that continued further down the aqueduct. But if a failure occurred, say in the Northern Division, or if that division needed simple cleaning or maintenance, then "togetherness" would give way to independent action. Gate-keepers could close the Northern Division's influent gate and close the equalizing pipe in the dividing wall. While the Northern Division drained, water would continue to enter and leave the Receiving Reservoir through its Southern Division.

The Receiving Reservoir was asymmetrical. The Northern Division covered four city blocks, and the Southern only three. But although they differed in area, the divisions were nearly equal in capacity, because the Southern held water at a greater depth. It held 25 feet of water while the Northern held only 20. This peculiar arrangement resulted from the natural lay of the land on York Hill. The northern end of the hill provided Jervis with much higher ground than he needed or wanted. Here, instead of raising walls to enclose the Northern Division, the Chief Engineer literally had to sink most of the structure into the hill, and because the hill was essentially solid rock, this excavation entailed heavy expense. To help trim this expense, Jervis decided to cut the northern end of the hill just far enough to provide him with 20 feet of standing water, instead of the 25 feet he really wanted. The southern end of the hill was lower to begin with, so by both excavating and raising walls, Jervis obtained a deeper basin for the Southern Division.

The architectural style of the massive reservoir is worth noting. No stylistic catchwords used to describe American architecture of the period fit it. The Chief Engineer would have called the reservoir "plain and substantial." Yet in one way Jervis did relieve the appearance of total utilitarianism and the tediousness of the structure's heavy, rough-hammered stone facing. He called for railings. He capped the reservoir with a green path, 18 feet wide, that visitors could stroll along while enjoying the view of this man-made 31-acre pond.

Below the Receiving Reservoir the aqueduct's line crossed two miles of very irregular terrain before reaching the Distributing Reservoir. As Jervis noted:

> From the Receiving Reservoir south, the country falls so much below the grade level as to leave no doubt in my judgement, of the propriety of continuing the aqueduct, by means of iron pipes, to form the connection between the receiving and distributing reservoirs. [35]

Jervis was so convinced of the need for iron pipes along the aqueduct's home-stretch that he never bothered to estimate the cost of crossing it with an embankment or bridge. Instead, he concentrated on the question of how many pipes he should lay between the two reservoirs. To decide this question, Jervis first had to estimate how many persons the Distributing Reservoir would ultimately supply with water, and what their daily per capita consumption would be. In his December 27 report, Jervis provided the Water Commissioners with his figures:

> It may be estimated that 700,000 people will ultimately derive their supply from the distributing reservoir on Murray's Hill, which will depend on the connecting pipes under consideration. At 30 [Imperial] gallons for each inhabitant, 21 millions will be required for the daily supply.[36]

Planning once again to use 36-inch pipes, Jervis initially supposed that three pipes, with a fall of six feet between the reservoirs, would be sufficient to meet lower Manhattan's needs. Later, however, he decided that the fall between the reservoirs could be reduced to only four feet. And, as usual, he recommended that only two pipes be laid at first, saving the expense of a third pipe for later.

The Chief Engineer intended for the effluent gates at the Receiving Reservoir to be mormally open, providing a constant flow of water into the pipelines. Where the pipes bottomed out in three locations, he located stopcocks and wasters. Where they rose on two peaks, he provided cocks to bleed any air caught in the pipes. After rising and falling for two miles, the pipelines terminated at the Distributing Reservoir on Murray Hill.

Unlike the York Hill reservoir, the Distributing Reservoir was not, primarily, a storage facility.[37] Its primary function was to improve the efficiency of the city's future distribution system by providing an elevated head of water <u>as close as possible</u> to the population it would serve. Major Douglass had chosen the Murray Hill site, on the west side of 5th Avenue, between 40th and 42nd Streets, because south of Murray Hill, all high ground disappeared.

Jervis' Distributing Reservoir shared certain characteristics with his Receiving Reservoir.[38] In particular, the Chief Engineer provided a weir to waste surplus water automatically, and he split the structure into two divisions which could operate independently or in unison. Yet when compared with the York Hill structure, the Distributing Reservoir was diminutive. Four hundred and thirty-six feet square at its base, when filled with 38 feet of water the structure's capacity was about 24 million U.S. gallons, or only one-eighth the Receiving Reservoir's capacity. And the dissimilarities went far beyond questions of scale. Jervis enclosed the Receiving Reservoir with earth embankments faced with stone. When designing the Distributing Reservoir, he switched to masonry walls.

This switch was prompted by several considerations. Unlike the York Hill structure, much of which was sunk into the ground, virtually all of the Murray Hill reservoir stood above ground, so its walls had to be taller. Because they stood against 38 feet of water, instead of 20 or 25 feet, they also had to be stronger. If these had been the only considerations, Jervis could have used earthen embankments to enclose the reservoir. After all, he had closed off the northern side of the Croton Valley with an embankment, and that earth had to stand against as much as 50 feet of water in the Fountain Reservoir. But in the Croton Valley, and on York Hill, Jervis had had room for broad embankments. He did not have room on Murray Hill.

This site was none too large, and it was surrounded by streets which Jervis did not want to encroach upon. The walls for the Distributing Reservoir had to be tall and strong, but at the same time as thin as possible. Consequently, Jervis turned to hydraulic masonry.

After choosing his material, Jervis had to decide upon the proper cross-section for the reservoir's walls. He briefly considered the propriety of solid walls, but he dismissed the idea. Walls of solid hydraulic masonry would be very expensive, and the cement in the walls' interior might take a long time to set.[39] To avoid these liabilities, Jervis next turned to the idea of double-walling each side of the reservoir, using two narrow, parallel walls, instead of a single, thicker wall. He would fill the space between the two walls with stone chips and gravel.[40] While this type of double-wall probably would have worked, the Chief Engineer conceived of yet another plan which provided surer support for the innermost of the two walls.

Instead of using a compacted fill between the walls, he decided to connect them with masonry cross-walls. By turning a small arch in each cross-wall, Jervis gained another important advantage: the advantage of inspection. A man could walk inside the reservoir's walls and check for water leakage. The Chief Engineer certainly guarded against this problem. He specified that the reservoir's floor was to be 12 inches of concrete; over the concrete floor, and carried up against the walls, he laid puddled earth; over the earth, he laid 15 inches of hydraulic masonry. The chances of water penetrating all these barriers seemed slight, but Jervis nevertheless welcomed a means of discovering any leakage which did occur.

Besides differing from the Receiving Reservoir in its wall construction, the Distributing Reservoir differed in its style. It represented a major deviation from the Chief Engineers's architectural precepts. Jervis believed that a large work should appear, above all else, well-conceived and substantial. Its appearance should clearly demonstrate that its designer's mind was swayed most heavily by functional considerations. He wrote that a large structure should be "relieved only by such ornamental parts, as are necessary to the stability and preservation of the work." Indeed, the engineer believed that on a large work the application of ornamentation for its own sake could give "the appearance that some important parts. . . [had] been neglected." [41]

Nevertheless, Jervis embellished the facade of the Distributing Reservoir with an Egyptian cornice. He admitted that a plain rectangular cornice, costing $10,000 less, would "answer every purpose of usefulness," but in this rare instance he argued that there was more to consider. The reservoir would have a "commanding situation in the midst of a dense population."[42] It would serve as a symbol, as "a representative of a great work." For these reasons, Jervis felt that the reservoir on Murray Hill merited the architectural embellishment he had denied other structures.

The effluent pipes on the 40th Street side of the Distributing Reservoir connected with the water mains the city was laying in lower Manhattan. The Water Commissioners had been charged with building an aqueduct to deliver Croton water to New York. They had not been charged with the task of distributing that water throughout the city. Where the water mains began, John Jervis' responsibilities ended. So in the latter part of the winter of 1837-38, the Chief

Engineer believed he had already discharged his most pressing and difficult duties. Half of the aqueduct was under construction, and he had finished, or nearly finished, plans for the other half of the line. The Water Commissioners had already approved these plans, and early in the working season he could put the 3rd and 4th Divisions under contract. After that, his engineering department would only have to monitor the work until the Croton Aqueduct was completed. That, at least, was the plan. Unfortunately, things did not work out as well as the Chief Engineer had hoped. In particular, one of his engineering designs sparked a long and public debate, and another of his structures failed catastrophically, causing him the greatest embarrassment of his professional career.

NOTES--CHAPTER SIX

[1]Jervis, "Monthly Report," September 30, 1837, Jervis Papers. Also "Monthly Reports," April 29, and June 30, 1837.

[2]T.J. Carmichael to Jervis, May 6 and 13, 1837, Jervis Papers.

[3]These publications are found in Jervis' personal library.

[4]Jervis Memoranda Book, entries for May 22 and September 18, 1837.

[5] Besides visiting Captain Turnbull, Jervis acquired Drawings Accompanying the Report of Captain Turnbull on the Survey and Construction of the Alexandria Aqueduct (1838).

[6]Jervis, "Monthly Report," May 31, 1837, Jervis Papers.

[7]Jervis, "Names of Contractors and Results of the letting of 5th September, 1837" Jervis Papers; "Semi-Annual Report of the Water Commissioners," July 1 to December 30, 1837," Board of Aldermen Document No. 55 (New York, January 4, 1838), pp. 347-349.

[8]Jervis, "Report on Crossing Mill River Valley," June 5, 1837, Jervis Papers. (In the "Index" to the Jervis Papers, this document is incorrectly dated as having been written in January, 1837.)

[9]Ibid.

[10]Letter, Mary 17, 1840, Manuscript Collection, Sleepy Hollow Restorations.

[11]Document No. 55, p. 364; Jervis, "General Report," March 12, 1838, Jervis Papers.

[12]This report, in manuscript form, is found in the Jervis Papers; it was published under the same title in Doc. No. 55, pp. 389-406.

[13]Doc. No. 55, p. 392.

[14]Ibid., p. 393.

[15]Ibid., p. 392.

[16]Ibid., pp. 394-395.

[17]Jervis, "Navigation of Harlem River," March 1838, Jervis Papers.

[18]Doc. No. 55, p. 399.

[19]Doc. No. 55, p. 400. Also Jervis, Memoranda Book entry for December 12, 1837.

To be precise, Jervis terminated the pipes on a level 2 feet 3-1/2 inches below their start. Two feet of fall were added to the line's normal declivity of 13-1/4 inches per mile, which, over the run of the syphon bridge, amounted to 3-1/2 inches.

[20]Doc. No. 55, p. 406.

[21]In manuscript form, this document exists in the Jervis Papers. The report was published under the same title in Doc. No. 55, pp. 407-435.

[22]Doc. No. 55, p. 377.

[23]Ibid., pp. 423-424.

[24]Ibid., pp. 410-414.

[25]For more technical details regarding this structure, see Jervis, "SPECIFICATIONS of the manner of constructing the preparatory work to form a Foundation for large Iron Pipes ... across MANHATTAN VALLEY," September, 1838, Jervis Papers.

[26]Actually, Jervis added 3 feet of fall to the aqueduct's regular declivity across the valley, so the total fall amounted to approximately 3 feet 10 inches.

[27]Doc. No. 55, pp. 415-416.

[28]Ibid., p. 416.

[29]Ibid., p. 426.

[30]For a more detailed description of this structure, see Jervis, "Specifications: Clendenning Valley," September 1838, Jervis Papers.

[31]For more detailed information, see Jervis, "SPECIFICATIONS of the manner of building a RECEIVING RESERVOIR at YORK HILL," September, 1838, Jervis Papers.

[32]Doc. No. 55, p. 429.

[33]See Schramke, pp. 49-53.

[34]Jervis to McNair, April 24, 1841, Jervis Letter Book. In this letter, Jervis attempted to find out the cause of a breech in the Shaws Water Works' reservoir near Greenock, Scotland. He wanted to know if it had burst because of water pressure, or if it had been undercut by leakage or eroded by a spill-over.

[35] Doc. No. 55, p. 430.

[36] Ibid., pp. 430-431.

[37] Ibid., p. 432.

[38] See Jervis, "SPECIFICATIONS of the manner of building a DISTRIBUTING RESERVOIR on MURRAY HILL," September 1838, Jervis Papers.

[39] Reminiscences of JBJ, p. 129.

[40] Doc. No. 55, p. 432.

[41] Jervis, "Report on Sing-Sing Aqueduct Bridge," February 8, 1837.

[42] Jervis, "Report on Cornice for Distributing Reservoir," July 28, 1840, Jervis Papers.

CHAPTER SEVEN

On March 24, 1838, the Chief Engineer and the Water Commissioners advertised for bids on all the aqueduct's 3rd Division, Sections 54 to 79. They also advertised for bids on Sections 80 to 85, or that part of the 4th Division north of the Harlem River. Jervis received proposals until May 7, and he and the Commissioners received over thirty bids on some of the individual sections. The "competition was spirited, and the prices lower than those demanded at the previous lettings."[1] The Commissioners let the thirty-two sections between the village of Hastings and the Harlem River for $1,600,000. This left them with only twelve sections not under contract, and they hoped to get that work under way quickly. Unfortunately, their hopes were thwarted by a controversy over Section 86 -- the Harlem River crossing.

On January 4, in their Semi-Annual Report covering the second-half of 1837, the Water Commissioners had publicly endorsed their Chief Engineer's intention to build a syphon bridge across the Harlem.[2] They stressed the fact that it would cost a half-million dollars less than a high bridge. They emphasized that the syphon bridge could be constructed more readily, because its contractor would not have to sink numerous bridge piers, a type of work "attended with many unforeseen difficulties and casualties." And they expressed the belief that the syphon bridge would be safer from the dangers of water leakage, frost, and settlement. The Commissioners seemingly presented a strong case in favor of the inverted syphon, but it failed to convince some important people. Their report sparked a debate over the Harlem River crossing which was carried on in the press, in the Common Council, and in the State Legislature.

An anonymous author laid out the debated issues in a letter published in the New York American on March 9, 1838. This letter faulted the syphon bridge on several counts. From a stylistic point of view, it was unimpressive. It would "deprive the work of all that would render it an ornament to the city and the age in which we live."[3] Technically, the inverted syphon was a risky "experiment." It might fail to deliver the desired amount of water to Manhattan. Its pipes might deform or burst from the pressure of the water under transport, and they most certainly would corrode and be short-lived. But the syphon bridge's most serious fault, according to this letter, was that it would block off most of the Harlem and close the river to all traffic except those vessels small enough to pass through its 80-foot arch which rose only 50 feet above high water.

Stung by this criticism, the aqueduct's engineering department suddenly switched to public relations work. Jervis and his Principal Assistant, Horatio Allen, fired off their own letters to the press, and they rebutted the criticism point-by-point. Allen answered the charge that the syphon bridge lacked style, that it was not an "ornament." Allen did not deny the charge, because he knew it was true. Instead, he tried to turn the structure's utilitarianism to advantage. He praised Jervis for:

> the soundness of that practical judgment, which not lead away by the exciting magnificence of a structure on which one's name would be a justifiable object of ambition, wisely prefers a more humble, but more substantial, more certain, and more durable plan. 4

Jervis and Allen both refuted the allegation that the inverted syphon was an "experiment." They cited European precedents near Genoa and Lyon which had proved successful, and the Chief Engineer mocked the sophistry of anyone who believed that water would not flow in abundance through his iron pipes: "This is certainly a new position in hydraulics, and it throws the labors of Bosset, Drs. Buat, Prony, Etylwein, and Robison, into the background."[5] Allen, meanwhile, defended the structural integrity of the iron pipes and allayed the fear that they might burst: "By reference to 'Renwick on the Steam Engine,' it will be seen that such a pipe will bear without 'change of shape' a pressure of more than 800 pounds."[6]

One other engineer stepped forward to defend the inverted syphon: Frederick Graff, the highly respected superintendent of Philadelphia's Fairmount Water Works. Jervis had consulted Graff on the use of iron pipes, and it seems likely that the Chief Engineer encouraged Graff to speak out when their use became controversial. Graff was quoted in the New York Evening Post on March 13:

> The plan you have adopted in passing over Harlem River with iron pipes is, in my opinion, preferable to the high aqueduct. The manner [in which] you have planned the whole structure, together with the arrangement of the pipes cannot but succeed to give a copious flow of water. 7

In a letter published in the New York American, Jervis confronted what had become, and would continue to be, the crucial issue in the dispute over the Harlem crossing -- would the syphon bridge ruin navigation on the river? This issue caught the Chief Engineer totally by surprise. When designing his low bridge, he had given little or no thought to its impact upon river traffic, simply because there was no traffic. In the 1700's, ships' captains had avoided sailing the Harlem, because it followed a winding course and in places was only five feet deep. Since about 1800, they had stayed off the river for an even better reason. It was impassable, due to man-made obstructions. Jervis stressed this fact in his letter:

> There is at present no navigation west of McComb's Dam, nor has there been any for near[ly] forty years. It is now obstructed by the dam and bridge near the Spuyten Duyval Creek, called King's Bridge, and by the Fordham Bridge on one side of the aqueduct line, and by McComb's Dam and Harlem Bridge on the other side. 8

The opponents of the syphon bridge admitted that the Harlem River had long been useless as a commercial shipping route. Nevertheless, they wanted to scrub the structure in favor a bridge which would provide a higher and wider clearance for ships, because they hoped to improve the river. They wanted to dredge its channel and remove existing obstacles, or by-pass them with canals. Someday, they hoped, the Harlem would become an important connector between the Hudson and East Rivers, a connector that would spawn and support businesses and industries on the northern end of Manhattan. A certain percentage of these visionaries even backed their hopes with investments. They had purchased land on both sides of the river, speculating on a boom in the region's development.

Jervis did not share the speculators' dreams, but he recognized that they formed an influential group that had connections in both the Common Council and state legislature.[9] So in his letter to the American, the Chief Engineer attempted to appease this interest group. Although he fully believed the syphon bridge's 80-foot arch would suffice "for any navigation that may be anticipated," he offered to increase it span to 120 feet and its rise to 65 feet. With these changes, the arch could accommodate a much wider range of vessels, should the Harlem ever be opened to traffic. The speculators could keep their dreams; Jervis could keep his syphon bridge, in a modified form.

The first governmental body to pass judgment on the inverted syphon was the state legislature's Committee on Grievances. On April 5, the committee reported on a memorial it had received which sought, through a legislative act, the forced abandonment of the syphon bridge. The committee disappointed its petitioners; its members concluded that with a 120-foot arch, the syphon bridge would not interfere with any foreseeable Harlem River traffic.[10] Jervis and the Water Commissioners were particularly pleased to receive this support, because they already knew that the Common Council's attitude was far less favorable. On March 31, the Council's Committee on Roads and Canals had summoned Jervis to defend his structure, and the meeting had not gone well for the Chief Engineer:

> Committee complained that I ought to have gone forward with the High Bridge & saved all the trouble and discussion between the different plans -- intimating that I might be afraid of undertaking the High Bridge. 11

On April 23 the Committee on Roads and Canals, as expected, reported its displeasure with the syphon bridge. Its members again intimated that Jervis might be afraid of tackling a high bridge. "No want of experience," they wrote, was a "satisfactory reason against undertaking the work."[12] The committee found that the Chief Engineer's and Water Commissioners' reasons for favoring the syphon bridge were unimportant, when weighed against "the propriety of preserving the navigation of the river." Whigs and Democrats alike stood squarely with the speculators. They noted that the syphon bridge would decrease property values along the Harlem, It would permanently injure the river and therefore injure the commercial and industrial development of northern Manhattan. In concluding its report, the committee urged Common Council to:

> request the Water Commissioners, in constructing the aqueduct across Harlem River, to leave at least three hundred feet of the channel open . . . , and that they build the bridge over the river in such a manner as to allow the free passage of sloops. 13

On May 8, the Water Commissioners answered the Committee on Roads and Canals by submitting its own report to the Common Council. Legally, the Council could not demand the abandonment of the syphon bridge. Only the state legislature, which had created the Board of Water Commissioners, could do that. But the Commissioners felt obliged to honor the Council's opinion on this important matter, so they attempted to sway that opinion. They reiterated the structural and economic merits of the inverted syphon. They stressed that most vessels, short of 90- or 100-ton sloops, could pass easily under its enlarged arch. The bridge could handle the two-masted craft used around the city for transporting manure; nearly all 40- or 50-ton market boats; several hundred miscellaneous vessels then navigating the Hudson and East Rivers; and all steamboats. The Water Commissioners also raised the point that three years earlier, Common Council had approved their original plan for the aqueduct, and "an important part of the plan adopted by the Common Council, and ratified by a large majority of the electors of this city, was the crossing of the Harlem River by inverted syphon." 14

If the Council wished to withdraw its prior approval, the Commissioners said they would abide by the decision. But they urged the Council to decide between a high bridge and a low bridge as quickly as possible, so they could get on with the work. Unfortunately, the Commissioners got neither a quick decision, nor a final one. In mid-July the bicameral Council split on the issue. The Aldermen chose not to interfere with the Commissioners' plans; the Assistant Aldermen urged construction of a high bridge. Since no clear mandate came out of Council, the Water Commissioners went ahead on their own and instructed Jervis to implement the syphon bridge.

Jervis proceeded as directed. On October 9, 1838, the West Point Foundry Association successfully competed against six other American and three British firms and won the contract to furnish all the iron pipes needed on Manhattan, including those to be laid across the syphon bridge.[15] On October 23, Jervis and the Commissioners let contracts on the aqueduct's last twelve sections, numbers 86 through 97. These contracts amounted to $2,100,000 -- exclusive of the cost of the pipes to be supplied by the West Point Foundry. The Commissioners let Section 91, the Manhattan Valley crossing, for $142,000. They let Section 94, which included the aqueduct bridge at Clendenning Valley, for $298,000; Section 96, including the Receiving Reservoir, for $566,000; and the Distributing Reservoir, Section 97, for $360,000. Another contract valued at $360,000 went to Ellsworth, Mix & Co. for the syphon bridge across the Harlem River on Section 86.[16]

Jervis had received eleven bids on the syphon bridge, despite the fact that its undaunted opponents had published the following warning in several New York newspapers:

> Harlem River -- To Masons, Builders and Contractors . . . We the subscribers, owners of land adjoining the Harlem River and in the vicinity thereof, and interested in keeping the navigation of said river unobstructed; to prevent innocent contractors being injured by an agreement to erect said bridge for the Water Commissioners, do give the public notice, that we will use every means the law will justify, to prevent any and all persons obstructing the water at the natural channel of said river. 17

Because Ellsworth, Mix & Co. received the syphon bridge contract so late in 1838, the firm completed little work on the structure before winter set in. Actually, it was fortunate that the contractor got off to a slow start. The opposition, true to its warning, continued to hound the state legislature for an act blocking the syphon bridge, and by the end of 1838 Jervis was quite certain that the opposition would eventually win its way.

On December 29, Jervis summed up the situation in a letter to J.J. Abert, an engineer working on the Alexandria Aqueduct Bridge across the Potomac. Jervis had fought against the high bridge every step of the way. In the coming months he would continue to fight it. Yet in his letter to Abert, the Chief Engineer expressed a surprising aquiescence. All along, it seems, a part of Jervis had wanted the high bridge, which would "give prominence to professional character as a work of art."[19]

> It now appears the navigation is esteemed of so much importance (that is, the facilities of improving it) that it is quite probable we shall be required to construct the high bridge, or essentially to maintain our grade over the valley. I cannot say by any means that I regret this -- as you know Engineers are prone to gratify a taste for the magnificent when there is good reason for the execution of prominent works. 20

On May 3, 1839, the opponents of the syphon bridge finally won their way, when the state legislature passed "An Act Prescribing the Manner in which the Croton Aqueduct shall pass the Harlem River." The act stipulated that:

> The Water Commissioners shall construct an aqueduct over the Harlem River, with arches and piers; the arches in the channel of said river shall be at least 80 feet span, and not less than one hundred feet from the usual high water mark of the river, to the underside of the arches at the crown; or they may carry said aqueduct by a tunnel under the channel of the river, the top of which shall not be above the present bed of the said river. 21

For the Chief Engineer, it was literally time to go back to the drawing board, and on June 1, he presented a new plan for crossing the Harlem. His plan met, but did not exceed, the state legislature's requirements.

Jervis did not adopt the option of a tunnel under the river. He thought the construction of a masonry tunnel large enough to accept an inverted syphon with four 36-inch pipes would be a very uncertain process. To document the problems which might plague a Harlem River tunnel, Jervis cited the history of Marc Brunel's tunnel under the Thames in London:

> The history of this work is . . . such as to admonish us of the uncertainty in estimating for work done under a heavy pressure of water. It was commenced in 1825, and then estimated to cost 160,000 pounds sterling. November, 1837, 12 years after its commencement, there had been expended 264,000 pounds, and it was then estimated to require an additional sum of 350,000 pounds to complete it, which, if correct, will make the final cost 614,000 pounds, or near[ly] four times the original estimate. [22]

Jervis felt that under the best circumstances, a contractor might be able to construct a tunnel under the Harlem in four years at a cost of $424,000. But because he feared that serious construction problems would be encountered, he added fifty percent for contingencies. [23] This raised the estimated cost of a tunnel to $636,000, and there was no guarantee that its real cost would not rise far above that figure. In addition, Jervis believed a tunnel would incur high maintenance costs, because salt water would inevitably percolate through its masonry and rapidly corrode its iron pipes. So Jervis decided against a tunnel, and that decision left him with no alternative except to cross the Harlem with a high bridge.

Jervis already had a high bridge design on hand, the one he had worked out a year-and-a-half earlier at the request of the Water Commissioners. But that design exceeded the height requirement set by the state legislature, so he chose not to use it, at least not *en toto*. He designed a second, somewhat lower bridge. The second bridge retained some important internal features, such as hollow piers and the use of interior spandrel walls to support the deck; and its arches, piers, pilasters, parapets and water table exhibited a style consistent with that of its predecessor. Nevertheless, the Chief Engineer's second high bridge differed significantly from his first.

Of primary importance, it was twelve feet lower. Jervis dropped the undersides of the arches to the minimum height of 100 feet above high water, as demanded by the legislature. Because the bridge now fell short of maintaining the aqueduct's grade line across the valley, Jervis dispensed with the masonry conduit between its parapet walls and substituted a shallow inverted syphon which could carry water under pressure.[24] Jervis calculated that two 48-inch pipes could handle the masonry conduit's discharge of 60 million U.S. gallons daily, so he designed the bridge's deck to accept pipes of that number and size. But since he believed that New York would not need that great a discharge for upwards of fifty years, he chose to economize by initially laying two less-expensive 36-inch pipelines across the bridge. As with all of his inverted syphons, he started and stopped the pipes in influent and effluent gate houses, and he located waste cocks along their lowest level.[25]

In December 1837, Jervis had estmated that a high bridge over the Harlem would cost $936,000. In June 1839, he estimated that his modified high bridge would cost $837,000. So by reducing the structure's height, the Chief Engineer anticipated a savings of about $100,000. Still, his modified structure could hardly be called an economical means of carrying two iron pipes over the river. Jervis could have greatly reduced the cost of a high bridge only by substituting timber construction for masonry, and he chose not to do that. A timber bridge would decay too rapidly and it would always be vulnerable to a catastrophic fire. The Water Commissioners approved their Chief Engineer's new plan for the high bridge, but only with great reluctance, only because they had to "obey the law":

> We still apprehend much embarrassment in sinking piers 25 feet through mud and water, and in raising them up to the proper height for springing the arches; and we still believe, the plan proposed by us of a syphon bridge . . . , was the preferable plan, both as to its cost, security, permanence of structure, and ease of construction. 26

The Commissioners declared the Ellsworth, Mix & Co. contract for the low syphon bridge abandoned, paid that firm for the work it had done, and on June 15, 1839 advertised for bids on the high bridge. In preparation for contract work, the engineering department prepared meticulous plans for the structure, going so far as to produce working drawings which showed the dimensions and alignment of each stone in each bridge pier. On August 13, the firm of Law, Roberts and Mason won the high bridge contract with a surprisingly low bid of $755,000. [27]

By the end of 1839, when the Harlem or High Bridge was still in its nascent stage, contractors had already finished 54 of the aqueduct's 97 sections. They had completed 26 miles of the masonry conduit, finished 7 tunnels, 114 culverts, and laid 115,000 cubic yards of foundation wall and an equal amount of protection wall. The Water Commissioners reported that, "The progress of the work has rather exceeded than fallen short of our expectations."[28] They had paid requisitions amounting to almost four million dollars, and they expected to expend another five million to carry the aqueduct to completion. Jervis and the Commissioners hoped to see all the sections finished, excepting High Bridge, by the end of 1841 or at least by mid-1842. With so much work behind them, and with the long debate over the Harlem crossing finally concluded, they thought the aqueduct might be concluded routinely. Unfortunately, more trouble lay ahead.

On March 17, 1840, Governor Seward, a Whig, ousted Stephen Allen's Board of Water Commissioners and installed a five-member Whig Board chaired by Samuel Stevens.[29] The move was blatantly political, an attempt to spread the glory of finishing the aqueduct over to the Whig party, but at least the Governor chose an able man to succeed Allen. Samuel Stevens, like his predecessor, came to his position with a long history of involvement in New York's quest for an abundant water supply. While serving on the Common Council in the late 1820's and early 1830's, Stevens had been an outspoken advocate of a centralized, municipally-funded water system. Nevertheless, the change in the Board was a cause of great concern to Jervis, a Democrat who had achieved his professional success while working on state canal projects controlled by other Democrats in Albany.[30]

The Whig Board would have its own ideas about the aqueduct, and it might even want its own Ghief Engineer. The deposed Commissioners, bitter over their own removal, saw that a purge might also take Jervis off the project. Believing such a move would be unwise and unjust, in a report covering their last months as Commissioners they urged their successors to retain Jervis:

> We leave with them our efficient and highly esteemed Engineer, John B. Jervis, Esquire, for whose services in the successful prosecution of the work, the public are greatly indebted. The industry and ability with which he has conducted this great enterprise, will carry his name to future time . . . We cannot forebear expressing the hope, therefore, that our successors will avail themselves of the talents and acquired knowledge of Mr. Jervis, for the further prosecution of a work of so much importance to the city. 31

Immediately after taking their places on the Board, Stevens' men did go on a "head-hunting" expedition, but it was of short duration. The new Commissioners were naturally inquisitive as to why the aqueduct was costing at least twice as much as the original estimate, so they investigated the manner in which the first Board had let contracts. They examined account books, records of all bids received, and they questioned contractors, trying to find any hint of favoritism or graft.[32] The new Commissioners found no evidence of impropriety, but they did conclude that a few of the adopted plans were too expensive. They started to challenge those plans, and thereby set the stage for a possible confrontation with the Chief Engineer. But the confrontation never came about. The Whig Commissioners acted wisely and in good faith. They urged no cost-cutting measures which jeopardized the security of the work, so Jervis cooperated with them and altered some of his structures. The Commissioners believed that the Receiving Reservoir was unnecessarily large, that New York would not require such an abundant storage facility "for a century to come, if ever . . ."

Consequently, they ordered the abandonment of $75,000 worth of rock excavation in its floor, a move which reduced the structure's capacity.[33] They also ordered the elimination of $10,000 worth of excavation along the route of the pipelines between the Receiving and Distributing Reservoirs. The most visible cost-cutting alteration sponsored by the new Commissioners was seen at Clendenning Valley, where they chose to abandon the road arches over 96th, 97th, and 101st Streets.[34] Jervis substituted a solid foundation wall for these three arches, in order to gain an estimated savings of $52,000. In the summer of 1840 the Whig Commissioners raised objections to the costliness of one other structure along the line, and again their objections generaged no conflict with the Chief Engineer. The Board objected to the unnecessary expense of crossing the Harlem River with the High Bridge, and it made an abortive attempt to initiate a lower structure.[35]

Jervis' willingness to cooperate with the new Board's economy drive defused a potential conflict and preserved his position. In not too long a time, he and the Whig Commissioners established a working relationship based on mutual respect:

> Every day I was becoming more acquainted with the new board and they with me. I soon thought I saw in them a practical sagacity that would not allow them to do any very absurd thing, and I came to have great respect for some members of the board . . . 36

This working relationship, tenuous at first, grew stronger after surviving some serious tests. On July 18, 1840, the New York American called for the reinstatement of Major Douglass. The paper claimed that Douglass had originated the aqueduct's plans and that Stephen Allen's Democratic Commissioners had removed him not for professional reasons, but because they considered Jervis "an élève of the Albany Regency, a more suitable instrument to subserve their political interests than a Whig."[37] Douglass tried to regain the Chief Engineership in October, through a published letter which gained wide distribution.[38] He claimed his removal had been politically inspired, and he opined that the aqueduct would fail if left in his successor's hands.

Jervis was stung by this criticism. As he later noted, the Whig Commissioners, too, were affected by the criticisms which surfaced in 1840. Nevertheless, they retained him for the duration of the project:

> The criticisms of Major Douglass and others . . . made a strong impression on the board of commissioners. I well recollect one morning Mr. Samuel Stevens . . . came into the office (his desk and mine were in the same room) with an expression that indicated much anxiety. I was writing at my desk. I laid down my pen to see if I could ascertain the cause. Casual conversation ensued, which soon brought up the aqueduct. Mr. Stevens, with a significant sigh, remarked that it would be sad, if after spending so much money, the aqueduct should be a failure. I replied that it would be sad indeed; that I had no doubt of its success; that my experience and investigation gave me confidence; that it was impossible for me to explain to him, for he could not be expected to follow the scientific reasoning or see the force of experience and investigation gave me confidence; that it was impossible for me to explain to him, for he could not be expected to follow the scientific reasoning or see the force of experience in such matters; that he must have faith, and if he did not think I was capable of conducting the work successfully it was his duty to engage an engineer on whom the commissioners could rely. Here was a clear case for reinstalling Mr. Douglass if the board had thought proper. I took no measure to influence them other than by a strict attention to my duties as engineer of the works. It is well-known the board did not make the change. 39

While the tensions between Jervis and the Whig Commissioners subsided over the course of 1840, a controversy erupted between the Commissioners and the Democratically controlled Common Council over the issue of who should lay the city's water mains. Stephen Allen's

Board had never wanted or sought control over the 130 to 160 miles of pipe being laid. Only in a sense did the first Commissioners assist the city in this work, by sharing the revenue gained from the issuance of Water Stock.

In 1836 the legislature had authorized New York to issue 2-1/2 million dollars of stock to fund construction of the aqueduct. Periodically, as the work progressed the city went back to the legislature with requests to issue more Water Stock. On March 29, 1838, for example, New York received permission to issue an additional three million dollars worth. But not all of this revenue went to the Water Commissioners. The city diverted part of it into its own treasury to defray the costs of laying water mains. Under the provisions of an act passed by the legislature on March 24, 1838, this practice was perfectly legal.[40] But by 1840 the Whigs had gained control of the legislature, and they found the same practice unacceptable.

On April 27, 1840, the legislature granted New York permission to issue another three million dollars of Water Stock, but this time it attached a string. The city government could expend none of the revenue, even to cover the costs of water mains, without the approval of the Water Commissioners for each expenditure.[41] For the new Commissioners, this amounted to an invitation to step in and assume control of the pipe-laying efforts.

They did step in, and willingly -- too willingly, as far as the Common Council was concerned. Early in May the Commissioners charged, with justification, that the city was installing pipes too slowly (only 35 miles of pipe had been laid), and they instructed Jervis to draw up his own plan for a network of pipes to cover lower Manhattan. Common Council strongly objected to this abrogation of its responsibilities, and in August it countered the move by establishing a Croton Aqueduct Department with the power to contract for the laying of distribution pipes. The politicians fought over the issue until April, 1841, when the state legislature settled the dispute in favor of the Council's Croton Aqueduct Department. While the politicians had squabbled, Jervis and Horatio Allen had only half-heartedly proceeded with plans for a distribution system, because as Jervis admitted to the Commissioners: "I have no desire to increase the duties and responsibilities of my charge, and would greatly prefer to see the distribution well conducted without my aid."[42]

In the summer and fall of 1840, the Chief Engineer did not want to divert his attention to water pipes. They were an unwanted burden. He wanted to concentrate on completing the aqueduct, and in particular he wanted to concentrate on the serious problems which were being encountered at the High Bridge site.

When the contracting firm of Law, Roberts and Mason started sinking the piers for High Bridge, the company immediately ran into problems even more severe than Jervis had anticipated. The early soundings of the Harlem had predicted that all of the river-piers and at least half of the land-piers would be founded on rock. Unfortunately, this prediction proved very inaccurate:

> It had been supposed a rock foundation would be found for the piers of the bridge. Rock in places was found on each side of the river, and though the soundings in the river had not in all cases met rock, it was supposed it would be found within limits that could be reached. But more thorough examination failed to show rock in some places after going eighty feet below high water.

> What was originally supposed in some cases to be rock . . . proved to be only large boulders that lay very thick in the mud and sand, and below these a bed of sharp sand. [43]

The existence of numerous 4,000- to 12,000-pound boulders posed one problem for the contractor and the Chief Engineer; the lack of a solid rock floor in the valley posed another. In order to sink a river-pier, Law, Roberts, and Mason first had to lay bare its riverbed site by enclosing it within a box-like coffer dam. Driven into the river's bed, and rising three feet above high water, each coffer dam was to serve as an impervious barrier. Once a steam-driven pump evacuated the inside of the dam, the space was to remain dry so men could enter the structure to work on a pier's foundation.

The boulders interfered with the installation of the coffer dams. The contractor used a heavy, falling weight to drive each dam's 9- to 12-inch thick sheeting timbers into the riverbed. When these timbers struck a boulder, despite their size they often splintered to pieces, or else they came to rest in such a way that water too easily found its way into the dam's enclosed working space. Consequently, a great deal of time and effort had to go into the arduous task of "lewising" the boulders. [44] Workers drilled a hole into a boulder, sunk a metal plug into the hole, attached a line, and then, using a portion of the coffer dam as a support, hoisted the boulder out of the way.

While the task of removing boulders prolonged the construction time of High Bridge (which was not completed until 1848), the lack of bed-rock in the valley threatened the stability of the entire structure. Several of the piers were founded on gneiss or marble, but five of the land piers and five river piers had to stand on groups of tapered, oak piles driven thirty to forty-five feet into sand. Jervis knew that many bridges had been constructed on piles, but none of them, to his knowledge, had been as large or as heavy as High Bridge. Under its great weight he feared that the piles might yield or sink unevenly, causing cracks in the masonry. He had no precedent to allay this fear; he "could find no specific experiments that warranted full confidence for this bridge." [45]

For Jervis, the conservative builder, this represented the worst kind of predicament. He could not bring himself to go on with the work, blindly hoping for the best. Before he would allow Law, Roberts and Mason to start raising piers, he had to assure himself that the piles would provide the structure with firm support. In order to gain this assurance, he instructed Horatio Allen to determine experimentally the load that a pile could bear without permanently yielding. Jervis apparently designed the experiment, but his Principal Assistant did all the calculations and worked out the mechanical details.

In May and early June, 1840, Allen experimented on four different piles which had been driven into sand by a 1200-pound hammer falling from a height of 30 feet. [46] To test-load each pile he used a hydrostatic press of his own design. He positioned the press directly over the pile, and to check the upward thrust of the press he fastened it down with heavy timbers and with iron straps bolted to a number of adjacent piles. Before he actually applied any load, Allen attached a long lever to the pile which indicated and magnified any movement. If the pile sank one inch, the lever moved 20 inches.

With the apparatus in position, Allen started a pump which forced water into the press and activated two rams. The larger "working" ram, 12 inches in diameter, bore directly against the head of the test pile. The smaller "calibration" ram, only eight-tenths of an inch in diameter, bore against a lever carrying weights of up to 1300 pounds. Because the cross-sectional areas of the rams varied by a factor of 228, so did their respective pressures. At all times the working ram exerted a pressure 228 times greater than the calibration ram. Allen used this relationship to determine just how much load he was applying to the pile. Assume, for example, that he loaded or held down the calibration ram with a weight of 500 pounds. At the instant the small ram started to lift the 500-pound weight, Allen knew that the working ram was exerting a load of 114,000 pounds on the head of the pile (228 times 500). By noting the position of the indicator, he also knew if the pile had yeild-ed under the load.

As a result of Allen's experimentation, Jervis confidently went ahead with High Bridge, believing it would stand safely on piles driven into sand. Allen concluded that as long as a pile yielded less than one inch under the last blow of the 1200-pound hammer which drove it into the ground, then it would not sink or permanently yield under a weight of less than 60 tons. Since the large piers would stand on many piles, clustered together, that load-bearing capability was sufficient to support the bridge. But although Jervis had gained confidence in the structure, he knew that he and his engineers had to exercise great vig-ilance over its progress. The new Water Commissioners, too, quickly came to appreciate the magnitude of the problems involved in constructing High Bridge:

> It is a fact not to be disguised that the erection of this bridge is not only a <u>stupendous</u> but is a <u>Herculean</u> task for our city to execute, and requires more engineering talent, inspection, and watchfulness than any other part, or we might almost say, all

the other parts of the aqueduct put together.[47]

All things considered, 1840 was not an easy year for the Chief Engineer. He had faced the change in the Commissioners, public criticism, and the problems at the Harlem River crossing. But by the end of the year Jervis appeared to be out of the woods. Contractors had completed more than three-fourths of the line. With the exception of Croton Dam, which was nearly done, they had finished the 1st Division, and the engineers had tested it. Several times in the fall, Edmund French had sent water from the dam to the waste weir in Sing-Sing. The 2nd Division was completed, except for Mill River Culvert. The 3rd Division was done, and so were all of the sections in the 4th Division north of the Harlem River. At the Harlem, Law, Roberts & Mason had successfully sunk four coffer dams and raised two piers above high water. On Manhattan, contractors had not carried their work as far as their counterparts in Westchester, but the Manhattan Valley crossing was half-done; Clendenning Valley was two-thirds of the way to completion; and both reservoirs were half-finished.

In their <u>Semi-Annual Report</u> covering from March to the end of December, 1840, Samuel Stevens' Water Commissioners expressed satisfaction with this progress, and they also expressed confidence in their Chief Engineer and his designs. For example, they said the Croton Dam was "believed to be durable in its character, and possessed of sufficient strength to resist the Croton . . . , a stream occasionally rendered by freshets, very powerful and turbulent."[48]

The Commissioners could not have known it, but in their evaluation of Croton Dam they unwittingly foreshadowed the next crisis which Jervis faced. The new year began with a catastrophe. On January 8, 1841, Edmund French wrote his Chief Engineer:

> I am sorry to inform you that the water about 3 o'clock this morning rose over the top of the embankment of the dam and in a few minutes swept the whole embankment and protection wall away. The masonry of the dam alone is standing. 49

It had been a snowy winter along the Croton. In the first days of January, 15 to 18 inches of snow lay along the frozen river and its feeders. Then, on January 5, the weather warmed, and as the snow and ice began to melt, it started to rain. For 48 hours it rained incessantly, and by January 7 a disastrous flood rushed down the Croton towards the aqueduct's Fountain Reservoir. An immense amount of water passed over Croton Dam, but the masonry weir was not long enough. It could not discharge water as fast as it was arriving, so the water in the Fountain Reservoir rose at a rate of 14 inches per hour. Finally, at 3 o'clock in the morning of January 8, the water stood 15 feet above the weir and began passing over the embankment which closed off the northern side of the valley. The rushing water washed the embankment away and spilled down the Croton. It destroyed homes, bridges, and small industries. Three persons drowned in the worst flood in the river's history.[50]

An embarrassed and regretful Chief Engineer journeyed to the dam with Samuel Stevens to inspect the damage:

> On passing over the hill as the road entered [Croton] valley, the view was indeed sad and the aspect was severe in the extreme . . . No one without such experience could imagine the severity with which this scene, with its attending circumstances, affected me. 51

Jervis took some solace in the fact that masonry had held in the face of the great flood. He took solace in the fact that if the catastrophe had to happen, at least it was best that it happened when it did, before New York had become dependent on the aqueduct for its water. But Jervis was not long in mourning. He had to correct his all-too-obvious error as quickly as possible, so the aqueduct could open by the middle of 1842. In his early designs for Croton Dam, Jervis had avoided carrying its masonry beyond rock and onto gravel, because to his knowledge no masonry dam as tall as this one had ever stood on gravel.[52] But now he had no choice except to build on gravel, in order to make the overflow weir longer.

Jervis designed a 180-foot-long extension for Croton Dam. He founded the extension on interlocking timber cribs filled with stone, placed along both sides of a solid wall of hydraulic masonry, which, during the initial phases of construction, had served as part of a coffer dam used to enclose the work site. The most notable feature of the extension was the face of the overfall. Jervis had taken great precautions to break the fall of water passing over the original dam, founded on rock. For the extension, standing on gravel, he recognized an even greater need to prevent falling water from undercutting the masonry:

> The idea occurred to me that some plan must be adopted by which the water in its passage from the lip of the dam could be turned gradually from a vertical to a horizontal position by the time it reached the apron . . . . I finally hit upon the plan of forming the lower face of the masontry on an O.G. [ogive] or reversed curve that would carry the water down on a smooth volume from its starting at the lip to the apron . . . This method was very favorable in modifying the form and giving a direction more easily managed to this heavy column of falling water . . . 53

In addition to using a reversed curve for the overfall, Jervis checked the falling water by placing a low secondary dam 300 feet below the main dam. The secondary dam created a pond of still water which rose just above the main dam's apron. This pool broke the force of the water passing over the weir by preventing it from falling off the apron and impacting directly on the river bed.

Within a few months of the flood, Jervis let a contract on the addition to Croton Dam which amounted to $127,000, and McCollough, Black, Hepburn & Co. energetically began the work.[54] Jervis' worst hour as an engineer had passed, and his finest hour was to come in a year's time, when he opened the Croton Aqueduct.

On June 8, 1842, the Water Commissioners, Jervis, Horatio Allen, and several other members of the Engineering Department met at Croton Dam. They entered the gate-house beside the dam and descended into the aqueduct for an inspection tour. Between June 8 and June 10 the men walked the 33 miles of the conduit from the dam to the Harlem River.[55] When they exited at the influent gate-house at High Bridge, they inspected the 36-inch pipe that had been laid across the Harlem on top of the coffer dams which surrounded the unfinished bridge piers. This temporary pipe would carry water over to Manhattan until High Bridge was completed. On June 22, Jervis and three assistants again inspected the conduit in Westchester County, but this time they did not walk it. The headgates were opened, allowing 18 inches of water to course down the aqueduct. The four-man party climbed aboard a small boat dubbed the "Croton Maid," and they floated down to the Harlem River.

In the course of these last inspections, the engineers discovered few flaws in masonry, only small fissures easily sealed with hydraulic cement. The structure was sound and could be put into service. On June 27, the engineers opened the gates to the Receiving Reservoir's Northern Division, and for the first time Croton water began to fill the man-made basin. A 38-gun salute heralded the arrival of the water.

New York's Mayor Morris attended the celebration, as did Governor Seward, the Water Commissioners, members of Common Council, and other dignitaries.

Jervis, cautious as always, let water proceed down the system gradually, making sure that each part of the line was indeed ready to receive it. On July 2, he opened the Receiving Reservoir's effluent gates and let water flow into the iron pipes leading to the Distributing Reservoir. On July 4, early in the morning when the dignitaries were still in bed, Jervis rallied his engineers to oversee the opening of the aqueduct's southernmost structure. One of his assistants, Fayette B. Tower, a man infintely more romantic than the Chief Engineer, described the scene:

> At an hour when the morning guns had aroused but few from their dreamy slumbers, and ere yet the rays of the sun had gilded the city's domes, I stood on the topmost wall of the reservoir and saw the first rush of the water as . . . [it] entered the bottom and wandered about, as if each particle had consciousness.[56]

Throughout July 4, New Yorkers strolled along the top of the Egyptian-styled reservoir and watched it slowly fill with Croton water. Within a matter of days, as soon as the Distributing Reservoir was sufficiently filled, Jervis opened its effluent gates and water ran into the city's mains. The city had not yet laid all needed pipes, and few property owners were hooked up to the system. But the city's Croton Aqueduct Department continued to lay mains; plumbers advertised the advantages of inside plumbing; hydrants stood out on street corners; and a number of fountains sent the Croton water 40 to 50 feet into the air. The distribution system was incomplete, but the aqueduct was nevertheless a visible success, a success which the city officially celebrated on October 14.

On that day, church bells and cannon fire resounded throughout New York. Thousands of citizens lined the streets to watch a long parade headed by barouches carrying the Governor, the Mayor, Samuel Stevens, Stephen Allen, other members of the Whig and Democratic Boards of Water Commissioners, and Common Council members. Companies of soldiers and firemen followed on foot. The parade ended at City Hall, where public officials pronounced the magnificence of the Croton Aqueduct. John Jervis, too, had ridden at the front of the parade, but the day really did not belong to him, to his engineers, or to the "worthy mechanics with the hammer and trowel, who laboured in the construction of the noble work."[57] The day of public celebration belonged to the politicians. But if Jervis felt at all slighted, he could take satisfaction in reflecting on the most-recent Semi-Annual Report put out by the Whig Commissioners, the men who for a time had considered removing him from his position:

> in an especial manner we are indebted to him [Jervis] for the great attention and untiring industry and talent he has brought to bear in the successful execution of this work, which will remain an enduring monument of his judgment and skill . . . [58]

NOTES -- CHAPTER SEVEN

1
"Semi-Annual Report of the Water Commissioners, January 1 to June 30, 1838," Board of Aldermen Document No. 5 (New York: July 2, 1838), pp. 49-50.

2
Document Number 55, pp. 371-72.

3
Quoted from Blake, Water for the Cities, p. 153.

4
Ibid., p. 153.

5
The quote is from a letter written by Jervis which appeared in the Journal of Commerce. See clipping in Jervis Memoranda Book, entry for March 17, 1838.

6
See clipping in Jervis Memoranda Book, entry for March 17, 1838.

7
Quoted from Blake, Water for the Cities, pp. 153.

8
Clipping, Jervis Memoranda Book, entry for March 17, 1838. The manuscript text of this letter is found as "Navigation of Harlem River," March, 1838, Jervis papers.

9
Reminiscences of JBJ, pp. 126-127.

10
Blake, Water for the Cities, pp. 153-154.

11
Jervis Memoranda Book, entry for April 2, 1838.

12
Committee on Roads and Canals, "Report," Board of Aldermen Document No. 88 (New York, April 23, 1838), p. 621.

13
Ibid., p. 627.

14
Water Commissioners, "Communication relative to the Croton Aqueduct," Board of Aldermen Document No. 2 (New York, May 14, 1838), p. 32.

15
Jervis, "Original Draft of Notice respecting Cast-Iron Pipe," May, 1838, and "Form of Contract for Cast Iron Pipe," October 9, 1838, Jervis Papers.

The Water Commissioners agreed to pay the foundry $70 per ton for straight pipe, and $75 per ton for curved pipe. The pipe was to be cast in a vertical position from remelted pig iron and proof-tested before delivery.

16
"Semi-Annual Report of the Water Commissioners, July 1 to December 31, 1838," Board of Aldermen Document No. 25 (New York, December 31, 1838), pp.238-239.

17
Ibid., p. 253.

18
Jervis to Mix, Searle & Co., December 4, 1838, Jervis Papers.

19
Reminiscences of JBJ, p. 143.

20
This letter is found in the Jervis Letter Book.

21
Acts of the Legislature . . . Croton Water, pp. 20-21.

22
"Report of the Chief Engineer on Plans for Crossing Harlem River," Board of Aldermen Document No. 10, (New York, July 1, 1839), p. 152.

23
Ibid., p. 154.

24
Ibid., p. 144.

25
Jervis made other changes in the high bridge, besides dropping it 12 feet and adopting an inverted syphon. For example, the superstructure he designed to support iron pipes was lighter and less massive than the one he had designed to support a masonry conduit. Because the superstructure was lighter, he also was able to diminish the thickness of the arch stones. One other change was the reduction in the number of the arches from 16 to 15. In his original high bridge plan, Jervis had called for "transitional arches of 60 and 70 feet to stand between the arcades of 80- and 50-foot arches. He eliminated the "transitional" arches in his second high bridge and went only with arches spanning 80 and 50 feet.

26
"Semi-Annual Report of the Water Commissioners, January 1 to June 30, 1839," Document No. 10, p. 126.

27
"Semi-Annual Report of the Water Commissioners, July 1 to December 31, 1839," Board of Aldermen Document No. 42 (New York, January 6, 1840), p. 442.

28
Ibid., pp. 439-441.

29
Other appointees to the new Board of Water Commissioners were John D. Ward, Zebedee Ring, R. Birdsall and Samuel Childs.

30
Jervis totally disclaimed the idea that he was a "political" engineer. In his Reminiscences, p. 156, he wrote: "In no way had I ever attempted to make politics a basis or means of occupation." While his allegiance to the Albany Regency certainly did him no harm in developing his career, it does seem the case that Jervis eschewed mixing politics and engineering. For instance, Jervis hired a Whig, Horatio Allen, as his Principal Assistant. And there is no mention of politics in any of the letters to and from Jervis which deal with openings in the aqueduct's engineering department.

31
Board of Aldermen Document No. 65 (New York, March 30, 1840), p. 645.

32
Reminiscences of JBJ, p. 155.

33
"Semi-Annual Report of the Water Commissioners, March 20 to December 31, 1840," Board of Aldermen Document No. 39 (New York, January 11, 1841), p. 518.

34
Water Commissioners, "Resolution," July 10, 1840, Jervis Papers; also Document No. 39, pp. 518-521.

35
Document No. 39, pp. 524-526.

36
Reminiscences of JBJ, p. 157.

37
Quoted from Blake, Water for the Cities, p. 159.

38
New York Courier and Enquirer, October 28, 1840; New York Times & Star, October 30, 1840.

39
Reminiscences of JBJ, p. 167.

40
Acts of Legislature . . . Croton Water, p. 20.

41
Ibid., pp. 21-22.

42
Jervis to Samuel Stevens, October 13, 1840, Jervis Letter Book.

43
Reminiscences of JBJ, p. 143.

44
Ibid., p. 144, 146-47.

45
Ibid., p. 144.

46
"Report of H. Allen on his experiment in Driving & the resistance of piles at Harlem Bridge," June 9, 1840, Jervis Papers. In Reminiscences of JBJ (fn., p. 144), Neal FitzSimons notes that, "This experiment may well have been the first full-scale test of pile foundations in the United States."

47
Reminiscences of JBJ, p. 148.

48
Document No. 39, p. 513.

49
French to Jervis, January 8, 1841, Jervis Papers.

50
"Appendix," Document No. 39, pp. 532-535.

51
Reminiscences of JBJ, p. 133.

52
Ibid., p. 134.

53
Ibid., p. 134.

54
For a description of how the contractor actually built the extension of the dam, see Reminiscences of JBJ, pp. 134-139.

55 "Semi-Annual Report of the Water Commissioners, January 1 to August 1, 1842), Board of Aldermen Document No. 9 (New York, August 8, 1842), p. 81.

56 Tower to Helen M. Phelps, July 5, 1842, John Wolcott Phelps Papers.

57 Tower to John Wolcott Phelps, October 10, 1842, Phelps Papers.

58 Document No. 9, p. 89.

EPILOGUE

> The great duty in taking care of the Aqueduct hereafter, will consist in a vigilant and intelligent watchfulness, by which small repairs made in proper time, will probably save it from expensive ones, that will be necessary if the work is allowed to become weak by the gradual process of deterioration that must inevitably follow protracted neglect. [1]
>
> John Jervis, 1849

> Now it should not be forgotten that all the works of men are subject not only to unforeseen imperfection, but to the corroding tooth of time, and therefore liable to fail. The present aqueduct has shown some failure, and has demanded attention, though it has for 40 years afforded, without material detention, a supply for the most part much greater than it was supposed necessary. [2]
>
> John Jervis, 1882

Before 1842, the citizens of New York City had lived for well over half a century with an inadequate supply of wholesome water. Because of this shortage, residents had been inconvenienced in their domestic lives and too little protected from the serious dangers of fire and disease. Then the Croton Aqueduct opened, and the city luxuriated in its bountiful water supply by erecting numerous fountains in public parks. New Yorkers were rightfully proud of their new aqueduct, the cost of which approached ten million dollars, with another two million dollars spent on distribution pipes. In 1842 it was the longest modern aqueduct in the world, and it performed well. When Jervis designed it, he expected a daily delivery of up to 60 million U.S. gallons. When he gaged its actual flow, he discovered that the masonry conduit could safely deliver up to 75 million gallons per day.[2] Since New Yorkers in 1842 consumed only one-sixth of that amount, the aqueduct appeared even larger than necessary. Citizens thought that the Croton Aqueduct would surely meet all of the city's water needs for years to come. Unfortunately, it did not.

In 1830, when New York began its successful drive for a municipally controlled water system, 202,000 persons resided in the city. In 1840, New York had 312,000 inhabitants. That figure swelled to 515,000 in 1850, and to 813,000 in 1860. After 1860, with the exception of the Civil War years, the city's population increased by an average of over 20,000 persons per year. In 1900, New York had 1,850,000 inhabitants.[4]

Just as the city's population increased at an astounding rate, so did the daily per capita consumption of water. Jervis and the Water Commissioners had estimated that each New York City resident would require no more than 30 gallons per day. But that estimate did not anticipate new industries which used increasing amounts of water. It did not anticipate all the fountains in the parks, or the mischievous, street-wise children who opened hydrants and left them running. And it certainly did not take into account the new amenities: private baths and showers, water closets and urinals. Finally, the estimate did not reflect the city's proclivity for wasting a resource, one it began taking for granted. Although not foreseen in the 1830s, wastage soon became a serious problem, as the President of the Croton Aqueduct Board reported in 1848:

> And how is the waste to be prevented? Who is strong enough to contend against the livery and omnibus stables, the constant running of fire and free hydrants, the street washers, the self feeding urinals in secret places, consuming about 600 to 1000 gallons every 24 hours, without any justifiable cause or motive, the public houses with large taps, and all the various sources of profusion and waste in the factories, streets, and buildings of the City? [5]

Users of the Croton water paid a hook-up fee and an annual bill. The bill was based on property size; there were no water meters to register actual usage. Consequently, with no economic incentive to cause users to conserve water, the pleas for conservation fell on deaf ears:

> The most unremitting and zealous exertions of the [Croton Aqueduct] department to abate the intolerable waste of water, have produced an effect scarcely perceptible to the public eye . . . [6]

The High Bridge over the Harlem River was completed in 1848 at a cost of $960,000. Within two years of the bridge's completion, New York had already reached a level of water consumption that Jervis had not expected it to reach until the 1880s or 1890s. Individuals used an average of 78 gallons daily, and the city as a whole consumed about 40 million gallons per day.[7] Because the demand for water continued to accelerate, the city soon encountered bottlenecks in its supply system wherever Jervis had installed pipelines.

In the 1850s and 1860s, the city laid more and larger pipes across Manhattan Valley and between the Receiving and Distributing Reservoirs.[8] During this time, the city also found itself short of water-storage facilities. The Receiving Reservoir--once deemed unnecessarily large--proved to provide an insufficient reserve during periods of drought. The reservoirs were so inadequate, in fact, that during some years the annual draining, inspection and repair of the aqueduct had to be abandoned.[9] The city could not afford to lose its running supply for even three to five days. To increase its water reserve, in 1858 the city contracted for a new

96-acre reservoir in Central Park that could pond over a billion gallons of water. Also in the 1860s the city began creating reservoirs along the Croton watershed above Croton Dam. These reservoirs captured water in the spring that could be released during the drier months of the summer.

In 1862 the city relieved the bottleneck at High Bridge caused by Jervis' use of two three-foot pipes. It laid a 90-inch main across the structure. For the first time, the full capacity of the masonry conduit in Westchester County could be carried across the Harlem River and into Manhattan. As a consequence, water usage rose dramatically.

In 1863, New York consumed 52 million gallons daily. Within a few years, consumption rose to above the aqueduct's maximum safe discharge of 75 million gallons, as determined by Jervis. The city continued to increase its supply of running water at greater depths in the masonry conduit. Six feet of water provided 82 million gallons daily in 1868. Six-feet-seven-inches brought 91 million gallons daily in 1872. In 1873, water ran at a depth of 7 feet 8 inches. It fell less than a foot short of the crown of the conduit's roofing arch. The daily running supply was nearly 105 million gallons. In this same year the "utmost capacity" of the aqueduct was figured at 115 million gallons.[10]

Instead of building a needed second aqueduct, in the 1860s and 1870s the city flirted with disaster by sending more and more water down the one aqueduct it had. By 1880, New York faced a two-fold water crisis. First, it needed far more water than the Croton Aqueduct could provide. Secondly, there was the very real danger that the physically abused aqueduct might fail catastrophically and cut off the city's water for a long period of time. Jervis had not designed the aqueduct to carry 105 million gallons per day. He had pared the amount of stone and brick in the conduit in order to trim its cost, and for a run totaling six miles across low areas, he had opted for a foundation wall laid dry, instead of a wall of solid hydraulic masonry. By 1880, in some low areas the foundation wall sagged as much as 12 inches, creating dangerous fissures in the conduit's floor and sides, and in many locations the roofing arch required concrete reinforcement, because it had cracked under internal pressures it was not designed to take. In a belated response to this crisis, Isaac Newton, then the aqueduct's Chief Engineer, readied plans for a new Croton Aqueduct capable of delivering an additional 300 million gallons daily.

While planning the new aqueduct, in 1882 Newton consulted John Jervis, then 87 years old and living in retirement on his farm in Rome, New York. After building the Croton, Jervis had served as a consulting engineer for Boston's Cochituate Aqueduct, and he had served as a chief engineer and officer of several railroad companies. The elderly engineer played no real role in developing the New Croton Aqueduct, aside from avowing the need for such a structure. In his 1882 consultant's report he censured the city for having waited so long to commence a second aqueduct;

> For several years, instead of adding to the supply as population increased, the overstrained capacity of the present aqueduct has been the same, and no addition has been practicable to the supply. A serious failure in the present aqueduct, which has been a source of anxiety for several years, may arrest its functions. 11

In his report, Jervis admitted that he had erred in adopting a dry foundation wall for the Old Croton, and he offered suggestions as to how its faulty sections could be repaired or bypassed.[12] It was clear, however, that in the main Jervis believed that mismanagement and poor maintenance, and not poor designs, had brought his aqueduct to its uncertain, fragile state.

When John Jervis died in 1885, the Old Croton still functioned as Manhattan's only important source of water. It carried this burden until the city opened the New Croton Aqueduct in 1891. The two aqueducts together thoroughly exhausted the resources of the Croton River, and yet Manhattan's population continued to swell, and the city grew by encompassing other boroughs. Consequently, as new water crises arose, New York had to go further and further to obtain additional water from such sources as the Catskill Mountain watershed and the Delaware River.

Jervis believed he had built the Old Croton Aqueduct to operate for centuries; it operated for a little more than one. In the first decades of the 20th century, some portions of the line were closed down for a time, and other parts, particularly on Manhattan, were drastically altered or demolished.[13] Still, the aqueduct continued to deliver water to the island--at a reduced rate of 35 million gallons per day--until 1955. For ten years after that, it delivered a mere trickle--.8 million gallons daily--to a Westchester community. Then on September 13, 1965, the head gates on the Old Croton were closed for good.[14]

Although the aqueduct did not come close to matching the longevity of some of the Roman aqueducts, it was by no means a failure. Despite some mistakes, Jervis had done a difficult job well. Although it may now be easy to fault the Chief Engineer and the Water Commissioners for the fact that the aqueduct too soon proved inadequate for New York's needs, such critical hindsight is unfair. John Jervis, an early engineer dedicated in his own way to changing the fabric of American life, could not have foreseen just how widespread and revolutionary some changes were to be. The engineer, after all, had no control over the dynamic growth of a city, and no control over the way its citizens chose to squander their water.

NOTES--EPILOGUE

1
Board of Aldermen Document No. 32 (New York, January 15, 1849), p. 620.

2
"Report of John B. Jervis on the Plans Proposed by Isaac Newton," New York Water Supply (New York, 1882), p. 4.

3
Reminiscences of JBJ, p. 130; Jervis to Stephenson, December 27, 1843, Jervis Papers.

4
Weidner, Water for a City, p. 54.

5
"Quarterly Report of the President of the Croton Aqueduct Board," Board of Aldermen Document No. 18 (New York, November, 1848), p. 359.

6
Report of the Croton Aqueduct Department (New York, 1850), p. 17.

7
Weidner, Water for a City, p. 56; Report of C.A. Dept., 1850, p. 17.

8
Reminiscences of JBJ, p. 149; Annual Report of the C.A. Dept., 1861, p. 20, 21; Annual Report of the C.A. Dept., 1866, p. 14.

9
Annual Report of the C.A. Dept., 1852, pp. 19-20; Annual Report of the C.A. Dept., 1861, pp. 7-8. Originally, the aqueduct was drained and inspected twice a year. This was cut to one inspection, and at times, to none.

10
See Department of Public Works, New York Water Supply (New York Water Supply (New York, February, 1882), pp. 45-46; and Third Annual Report of the Department of Public Works, 1873, p. 23.

11
"Report of Jervis on the Plans Proposed by Isaac Newton," p. 3.

12
Ibid., pp. 15-16.

13
Today, traces of the Old Croton Aqueduct are virtually nonexistent on Manhattan. The Main Branch of the New York Public Library stands on the site of the Distributing Reservoir, and the masonry conduit and

the road arches at Clendenning Valley are long gone--having been replaced by pipelines in the 1870s. High Bridge still stands, but in 1937 a single steel span replaced five of its masonry arches.

The Old Croton Aqueduct has fared better in Westchester County. Jervis' Croton Dam still exists--but stands under water. It was flooded in 1906 by the New Croton Dam. Other structures, thankfully, are still visible, such as Sing-Sing Kill Aqueduct Bridge, Mill River Culvert. (The last structure has been modified considerably.) The line of the aqueduct is now under the auspices of the Taconic State Parkway, and in many parts of Westchester it serves as a kind of recreational trail used by bikers and horseback riders.

14
Card file, "Old Croton Aqueduct," New York City Division of Water Supply Control.

APPENDIX I

"Inventory of Articles in
Office at Sing-Sing"

Source: Edmund French,
November, 1836, Jervis Papers

1 theodolite (missing 2 magnifying glasses)
1 level
1 compass
1 pair new level rods
1 pair old level rods
4 shod range rods
2 unshod range rods
1 large drawing board
2 second size drawing boards
1 third size drawing board
1 large drawing table
1 small office table
1 large office table
1 large stationery case
1 small bookcase
2 T-squares
1 four-foot rule
2 two-foot rulers
1 one-foot ruler
4 drawing horses
2 stools
1 100-foot chain
1 66-foot chain, 4 pins
2 chain stretchers
2 hatchets
1 stove, scuttle and poker
6 candlesticks
3 chairs
1 washbowl and pitcher
1 crowbar
1 tin map case
1 set of maps of line to Harlem
1 set of profiles
  profiles of ravines to Harlem
  profiles of tunnels
2 blank account books
1 large blank book
1 book of copies of payrolls

APPENDIX II

"Inventory of Articles belonging to the Commissioners of Water"

Source: Jervis, October 28, Jervis Papers

(Articles "placed under the care of the Chief Engineer.")

31 feet of boring rods with joints
1 auger
1 sounder diamond point
3 wrenches
2 keys for working the rods
1 pair of shears for working the rods
1 double, 1 single block and rope for working rods
1 pair leveling staff with targets
6 new marking pins
1 four-pole chain
1 chain of 100 feet
1 pair chain poles
1 pair mahogany leveling staffs
2 tape measures, 60 and 66 feet
1 plumb bob
1 leveling instrument, complete
2 tape lines measuring 66 and 90 feet
1 crowbar
1 spade
1 padlock
1 pickaxe
4 ranging staffs
4 draft boards
1 tin sauce pan and 3 tumblers
5 satinwood rules
2 T-squares
5 rods
1 small case
1 table and lock
2 benches, wall straps and hooks
1 map case
1 wash bowl, pitcher and broom
1 counter brush
1 large table
6 Japaned candlesticks
1 drawing table
1 surveyor's compass and tripod
1 box of colors
1 drawing table 12 feet long
1 drawing table 8 feet long
1 4-1/2-foot drawing board
2 pair wooden horses
6 large portfolios with leather flaps
1 pair leveling staffs

APPENDIX III

Engineering Department Roster
(September 1836 to March, 1840)

Sources: "Schedule of Pay," September, 1836; "General Report," March 12, 1838; "Report of Tour on Line," March 8, 1839; "Report on Organization of Engineer Department," March 20, 1840, Jervis Papers. Also, "Semi-Annual Report," January to June, 1837 and 1838.

Chief Engineer

Douglass, David Bates (1835-1836)
Jervis, John B. (1836 to completion)

Principal Assistant Engineer

Allen, Horatio (Born 1802, the son of Benjamin Allen, mathematics professor, Union College. Graduated from Columbia College, 1823. Before Croton project, worked on Chesapeake and Delaware Canal; Delaware and Hudson Canal; and Chief Engineer, South Carolina Railroad. After Croton project, proprietor of Novelty Iron Works, consulting engineer for Brooklyn Bridge, President of American Society of Civil Engineers.)

Resident Engineers

Anthony, Henry T. (Started as Assistant to Traverser on Douglass' 1833 survey.)

French, Edmund (Graduated West Point, 1828. Started as Assistant Engineer under Douglass.)

Hastie, Peter (Had served under Jervis on Chenango Canal.)

Jervis, William (John Jervis' brother; started out as first Assistant.)

First Assistants

Churchill, M. (Started as Leveller under Douglass.)
Crane, B. F.
Davidson, M. O. (Started as rodman under Douglass.)
Henry, John E. (Started as a rodman; had worked for Jervis previously.)
Lansing, A. B. (Perhaps started as Leveller under Douglass.)
Moffit, R. C. (Started as rodman.)

First Assistants (continued)

Renwick, James, Jr. (Son of renowned professor of science at Columbia College. Started as second Assistant. Later became noted architect, designer of St. Patrick's Cathedral in New York City, of Smithsonian Institution in Washington.)
Righter, C. A. (Started as rodman under Douglass.)
Tower, Fayette B. (Wrote Illustrations of the Croton Aqueduct, 1843.)
Tracy, Edward (Started as second Assistant; worked with Jervis on Chenango Canal.)
Zabriskie, J. J.

Second Assistants

Anderson, William
Anthony, Edward
Brook, L. (Started as rodman.)
Buchanan, William (Started as rodman under Douglass.)
Campbell, John (Started as rodman.)
Isherwood, B. F. (Started as rodman.)
Routon, Edward
Sickells, T. E. (Started as rodman.)
Wise, George O. (Started as rodman under Douglass.)

Draftsmen

Carmichael, Thomas J. (Started under Douglass; resigned in order to contract for work on aqueduct.)
Pearson, Charles
Schramke, Theoph (Wrote Description of the New York Croton Aqueduct, 1846.)
Wells, Joseph (Started under Douglass.)

(Inspectors of masonry and men who never rose above the rank of rodman are not listed.)

APPENDIX IV

Estimates of Three Means of Crossing Mill River

Source: Jervis, "Report on Crossing Mill River," June 5, 1837, Jervis Papers

Bridge with five 60-foot arches

	Cubic Yardage	$/ Yard	Amount
arches	875	25	21875
spandrels	2394	7	16758
water table	52	30	1560
masonry above water table	2689	10	26890
pilasters below water table	59	20	1180
piers	1888	15	28320
abutment walls	2424	10	24240
slope wall	624	2	1248
earth embankment	3686	.20	737
foundation wall	1436	2	2872
conduit arches	94	10	940
masonry, side walls	224	6	1344
cornice at spring of arch	42	25	1050
centering			3000
excavation of foundation			500
340 feet of cast iron lining @ $30/foot			10200
		TOTAL:	$142,714

Bridge with six 50-foot arches

	Cubic Yardage	$/ Yard	Amount
arches	779	22	17138
spandrels	2189	7	15323
water table	52	30	1560
pilasters below water table	52	20	1040
masonry above water table	2688	10	26880
cornice at spring of arch	42	25	1050
two solid piers	612	15	9180
three hollow piers	1548	15	23220
abutment walls	2424	10	24240
slope wall	624	2	1248
earth embankment	3686	.20	737
foundation wall	1436	2	2872
conduit arches	94	10	940
masonry, side walls	224	6	1344
centering			2500
excavation of foundation			500
340 feet of cast iron lining @ $30/foot			10200
		TOTAL:	$139,972

APPENDIX IV
(Continued)

Embankment with double culvert

	Cubic Yardage	$/ Yard	Amount
upper arch of culverts	596	20	11920
reversed arch of culverts	307	20	6140
abutments and pier	651	12	7812
parapets, wings and pilasters	130	12	1560
masonry between arches	404	6	2424
spandrel backing	102	6	612
embankment below grade	69161	.25	17290
backfilling above grade	5406	.25	1351
foundation wall	13193	2.50	32982
slope wall	3175	2	6350
brick arch, conduit	253	10	2530
side walls, conduit	590	6	3540
spandrel backing, conduit	65	6	390
concrete	124	6	744
excavation of foundation			500
timber foundation of culverts			1000
		TOTAL:	$97,145